

AD-A161 177

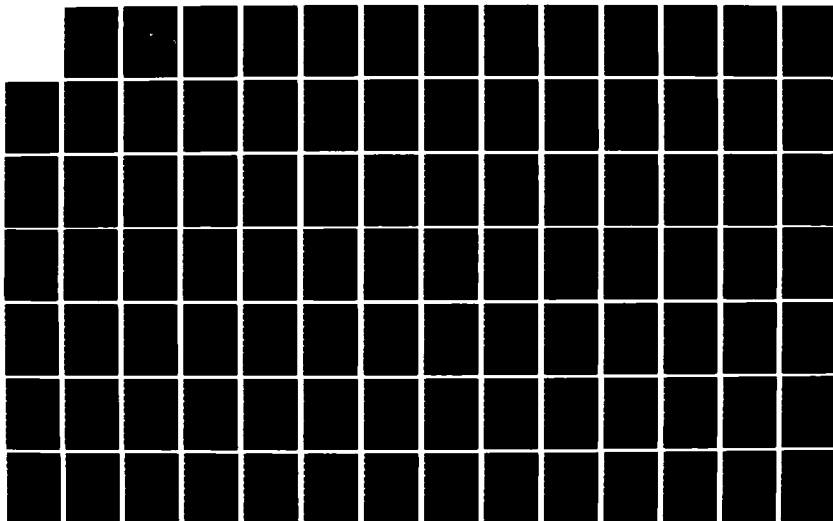
FASTS: A RADAR SIMULATION MODEL FOR THE DEVELOPMENT AND
ANALYSIS OF AIRCRAFT ANTI-SHIP TACTICS(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA F O BARRETT SEP 85

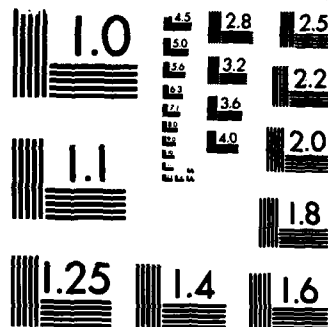
1/2

UNCLASSIFIED

F/G 17/9

NL



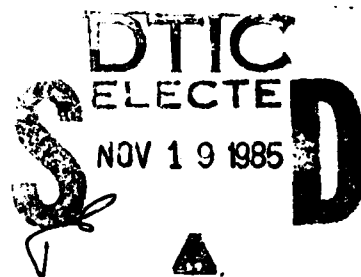


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A161 177

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

FASTS: A RADAR SIMULATION MODEL
FOR THE DEVELOPMENT AND ANALYSIS
OF AIRCRAFT ANTI-SHIP TACTICS

by

Frank O. Barrett III

September 1985

Thesis Advisor:

R. N. Forrest

Approved for public release;
distribution is unlimited

DTIC FILE COPY

11 18-85 045

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A161177	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FASTS: A Radar Simulation Model for the Development and Analysis of Aircraft Anti-Ship Tactics		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis September, 1985
7. AUTHOR(s) Frank O. Barrett III		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE September, 1985
		13. NUMBER OF PAGES 137
		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution is unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Radar; Simulation; War-at-Sea; IREPS		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This thesis describes an interactive computer program that was developed by the author. The program which is called FASTS simulates a many-on-many war-at-sea scenario involving ship based early warning radars, strike aircraft and supporting radar jammers. It provides the tactics designer a testbed for evaluating strike tactics against a defensive radar network and for estimating the impact of environmental conditions on radar detection.		

Approved for public release; distribution is unlimited

FASTS: A Radar Simulation Model for the
Development and Analysis of Aircraft Anti-Ship Tactics

by

Frank O. Barrett III
Commander, United States Navy
B.S., United States Naval Academy, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

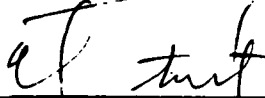
NAVAL POSTGRADUATE SCHOOL
September 1985

Author:

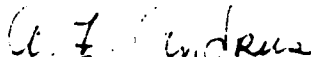


Frank O. Barrett III

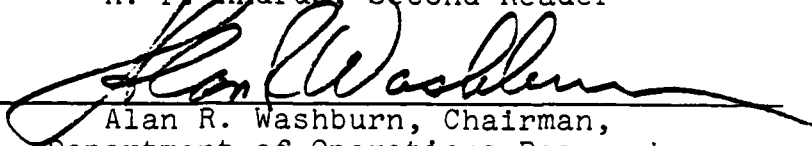
Approved by:



R. N. Forrest, Thesis Advisor



A. F. Andrus, Second Reader



Alan R. Washburn, Chairman,
Department of Operations Research



Kneale T. Marshall, Dean of
Dean of Information and Policy
Sciences

ABSTRACT

This thesis describes an interactive computer program that was developed by the author. The program which is called FASTS simulates a many-on-many war-at-sea scenario involving ship based early warning radars, strike aircraft and supporting radar jammers. It provides the tactics designer a testbed for evaluating strike tactics against a defensive radar network and for estimating the impact of environmental conditions on radar detection.

Accession For	
Full Text	<input checked="checked" type="checkbox"/>
Abstract	<input type="checkbox"/>
Indexing	<input type="checkbox"/>
By	
Distribution	
Availability Codes	
Avail. and/or Special	
A1	



TABLE OF CONTENTS

I.	INTRODUCTION -----	8
	A. RECENT DEVELOPMENTS -----	9
	B. THESIS RESEARCH OBJECTIVE -----	9
II.	BACKGROUND -----	11
	A. THE RADAR MODEL -----	11
	B. THE RADAR JAMMING MODEL -----	14
	C. RADAR ENVIRONMENTAL PROPAGATION LOSSES -----	15
	1. The Optical Region -----	16
	2. Diffraction Effect -----	16
	3. Refraction and Anomolous Propagation -----	17
	D. DETECTION MODEL -----	21
	E. OPERATOR FACTOR -----	23
III.	THE PROBLEM SOLUTION -----	26
	A. PROGRAM OVERVIEW -----	26
	B. INITIALIZATION SUBROUTINE (INIT) -----	27
	C. AIRCRAFT MODULE (UPDAC) -----	30
	D. RADAR MODULE (UPDRD) -----	32
	1. Path Losses -----	37
	2. Noise Power -----	39
	3. Signal Power -----	40
	4. Probability of Detection -----	42
	E. PROGRAM OUTPUT -----	42
	1. Data -----	43

2.	X-Y Plot -----	43
3.	Probability of Detection for a Scan Plot --	48
4.	First Detection Statistics -----	49
IV.	FASTS VERIFICATION -----	53
A.	LOSS COMPUTATION TEST -----	53
B.	RADAR HORIZON TEST -----	54
C.	JAMMER SELF-SCREENING TEST -----	55
D.	STANDOFF JAMMER TESTS -----	55
1.	Azimuth Test -----	55
2.	Range Test -----	56
V.	SAMPLE IMPLEMENTATION -----	60
A.	SCENARIO -----	60
B.	DATA FILE CONSTRUCTION -----	61
C.	PROGRAM EXECUTION -----	61
D.	EVALUATION OF RESULTS -----	66
E.	FOLLOW-ON SIMULATIONS -----	71
VI.	RESULTS AND CONCLUSIONS -----	72
APPENDIX A.	FASTS PROGRAM SOURCE CODE -----	74
APPENDIX B.	FASTS DATA INPUT GUIDE -----	124
LIST OF REFERENCES	-----	135
INITIAL DISTRIBUTION LIST	-----	136

LIST OF FIGURES

1.	The Optical and Diffraction Regions -----	15
2.	Horizon Extension Due to Defraction -----	17
3.	Radar Energy Propagation in a Surface-based Duct ---	19
4.	Required Signal-to-Noise Ratio for Detection with Noncoherent Integration of Pulses -----	20
5.	Path Loss for a 5000 MHz Transmitter at 90 Feet and a Receiver at 500 Feet for a Standard Atmosphere -----	22
6.	Probability of Detection versus Excess Signal- to-Noise Ratio for Probability of False Alarm of 10^{-6} and an Integration Factor of 10 -----	24
7.	FASTS Main Routine -----	28
8.	Subroutine UPDAC -----	33
9.	Subroutine UPDRD -----	35
10.	Subroutine IREP -----	38
11.	Radar Azimuth Antenna Patterns, Four Degree Beamwidth -----	41
12.	Subroutine OUTPUT -----	44
13.	FASTS Data Output -----	47
14.	FASTS X-Y Plot Output -----	48
15.	FASTS Probability of Detection per Scan Plot Output -----	49
16.	Subroutine Output-Stats -----	51
17.	FASTS Statistics Output -----	52
18.	Radar Horizon Test -----	54
19.	Standoff Jammer Test -----	57
20.	Sample Data File Listing -----	62

21.	X-Y Plot for Radar 1, 100 nm Scale -----	67
22.	X-Y Plot for Radar 2; 100 nm Scale -----	67
23.	X-Y Plot for Radar 1; 50 nm Scale -----	68
24.	X-Y Plot for Radar 2; 50 nm Scale -----	68
25.	Probability of Detection per Scan Plot for Radar 1 -----	69
26.	Probability of Detection per Scan Plot for Radar 2 -----	69
27.	First Detection Statistics for Simulated Missile ---	70

I. INTRODUCTION

Recent advances in ship anti-air defensive systems have brought about significant changes to the War-at-Sea (WAS) battle environment. Improved surface-to-air missiles are able to kill incoming raid aircraft at longer ranges and at lower altitudes. In addition, close-in weapon systems designed to rapidly engage and destroy penetrating raids and missiles are widely deployed and have demonstrated a measure of success, and supporting radar systems have grown in both power and countermeasures sophistication.

Efforts to improve aircraft strike capabilities while reducing attrition have been directed toward reducing the time the attacker is exposed to the hostile environment. These efforts have led to the incorporation of low altitude flight profiles and standoff jamming into strike tactics for the purpose of delaying or preventing initial detection and degrading the enemy's fire control solution.

The development and evaluation of effective coordinated strike tactics that incorporate low altitude flight profiles and standoff jamming for the multi-threat radar scenario has proven a challenging problem for planners. The constantly varying aircraft, jammer, and radar geometrical relationships and the complex effects of the atmosphere on radar propagation

are not easily analyzed and understandably often have given way to broad assumptions of capability which have led to standard, invariant and often sub-optimum tactics.

A. RECENT DEVELOPMENTS

The introduction of the Integrated Refractive Effects Prediction System (IREPS) into the fleet provided a major tool for the tactical exploitation of the effects of atmospheric conditions on radar propagation. By providing a shipboard capability to predict radar coverage and propagation anomalies; IREPS highlights altitudes of radar energy ducting and demonstrates that in many cases the use of low altitude attack profiles over water actually increased aircraft detection ranges. Similarly, the ducting of radar jamming energy can either magnify or reduce its effectiveness.

Additionally the vastly increased capability in computing power and speed brought about by the new generation of desktop computers is now at the disposal of the tactician. Complex simulation programs, which until now required a near main-frame capacity, can be conveniently run on small computers such as the HP-9000 series which are presently maintained in the fleet.

B. THESIS RESEARCH OBJECTIVE

The objective of the research described in this thesis was to develop a computer program that through simulation would provide a capability to predict the effectiveness of

shipboard radar performance against airborne targets in the presence of jamming and anomalous propagation effects. A program was developed which is called FASTS; its development and characteristics are described in what follows.

II. BACKGROUND

The basic issue to be considered in assessing radar detection of a target is the following:

Is the reflected radar energy from the target detectable when superimposed with jamming signals and receiver noise?

The following models for radar and jammer signal propagation, receiver noise, and target detectability were used to determine the probability of defection for airborne targets in FASTS.

A. THE RADAR MODEL

Through the years, various efforts have resulted in the development of descriptive models that predict the performance of radar (and radar jamming) systems. These models are not exact but they do permit meaningful and consistent analysis and as such are most useful.

Until the recent past, general practice has been to assume that the radar and target were located in free space since the non-free space signal propagation effects are considerably more complex and difficult to calculate. The use of computers to perform these calculations has made it possible to quickly evaluate non-free space propagation factors and improve the accuracy of the radar model.

The following is a development of the radar transmission equation. The forms are simplified to allow one to easily

identify the quantities which must be evaluated when considering environmental factors. This derivation follows from A Guide to Basic Pulse-Radar Maximum-Range Calculation by Blake [Ref. 1].

It is convenient to follow the path of the energy from its transmitter to the target and back to the radar receiver. If one can assume that a transmitting antenna radiates isotropically (uniformly in all directions), then the power density (watts per unit area) at any point at distance R is:

$$\text{Power Density at R} = \frac{P_t}{4\pi R^2} \quad (1)$$

where P_t is the total power radiated, and $4\pi R^2$ is the area of a sphere of radius R.

However since radar antennas are directional, the power density at distance R is:

$$\text{Power Density at R} = \frac{P_t G_t}{4\pi R^2} \quad (2)$$

where G_t is the on-axis gain of the transmitting antenna.

If a target at range R intercepts an amount of power contained in an area σ square meters and reradiates it isotropically, the power density returned to the antenna will be:

$$\text{Power Density at Receiving Antenna} = \frac{P_t G_t}{4\pi R^2} \sigma \frac{1}{4\pi R^2} \quad (3)$$

The receiving capture area of an antenna is, by definition, the ratio of power delivered to the radar receiver (P_r) to the field power density:

$$A_c = \frac{P_r}{\text{Power Density}} \quad (4)$$

For a receiving antenna gain of G_r , the capture area is:

$$A_c = \frac{G_r \lambda^2}{4\pi} \quad (5)$$

Combining equations (3), (4) and (5) yields:

$$P_r = \frac{P_t G_t}{4\pi R^2} \sigma \frac{G_r \lambda^2}{4\pi} \quad (6)$$

For radars using the same antenna for transmitting and receiving, G_t and G_r can be assumed to be equal, and thus, with rearranging the equation for radar transmission in free space becomes:

$$P_r = \frac{P_t G^2}{(4\pi)^2 R^4} \sigma \frac{\lambda^2}{4\pi} \quad (7)$$

When free space propagation conditions are not met, this equation will not give a correct result. A solution is provided by inserting into the equation a pattern-propagation factor F which accounts for wave propagation effects due to non-free space conditions and effects of the antenna pattern. When the same antenna is used for transmitting and receiving, the factors are identical and are combined. The equation can now be presented in the following form:

$$P_r = P_t G^2 \sigma \frac{\lambda^2}{4\pi} \left[\frac{F}{4\pi R^2} \right]^2 \quad (8)$$

where the bracketed quantity is composed of factors which are dependant on target and radar relative positions and represents the one-way transmission loss for the radar signal.

B. THE RADAR JAMMING MODEL

Noise jammers produce a signal which adds to the thermal noise already present in the radar receiver. The jamming noise power received is derived in much the same way as for the radar equation and is given by:

$$N = \frac{P_j B_r G_j G_r \lambda^2}{B_j L_p 4\pi} \left[\frac{F}{4\pi R^2} \right] \quad B_j > B_r \quad (9)$$

where P_j = Jammer Power

B_j = Jammer Bandwidth

B_r = Radar Receiver Noise Bandwidth

G_j = Jammer Antenna Gain

G_r = Radar Antenna Gain

F = Pattern Propagation Factor

R = Jammer to Radar Range

L_p = Polarization Loss Factor

The polarization loss factor included in Equation (9) is required when the polarization of the jamming system does not match that of the radar system. The loss factor would be infinite if the jamming antenna and the radar antenna could be perfectly cross polarized. In general the jammers will not have the same polarization as the radars. In order to accommodate a variety of polarizations, jammers are often either forty five degrees slant polarized or are circularly polarized resulting in an L_p of two. [Ref. 2:p. 3a-1]

C. RADAR ENVIRONMENTAL PROPAGATION LOSSES

The propagation of radar waves is affected by interaction with both the earth's surface and the atmosphere. Under certain conditions, environmental factors can substantially alter propagation factors and therefore be critical. It is necessary to distinguish between two different regions shown in Figure 1 when discussing radar propagation. One is the optical region which extends within the line of sight of the radar. The other is the diffraction region which lies beyond the horizon.

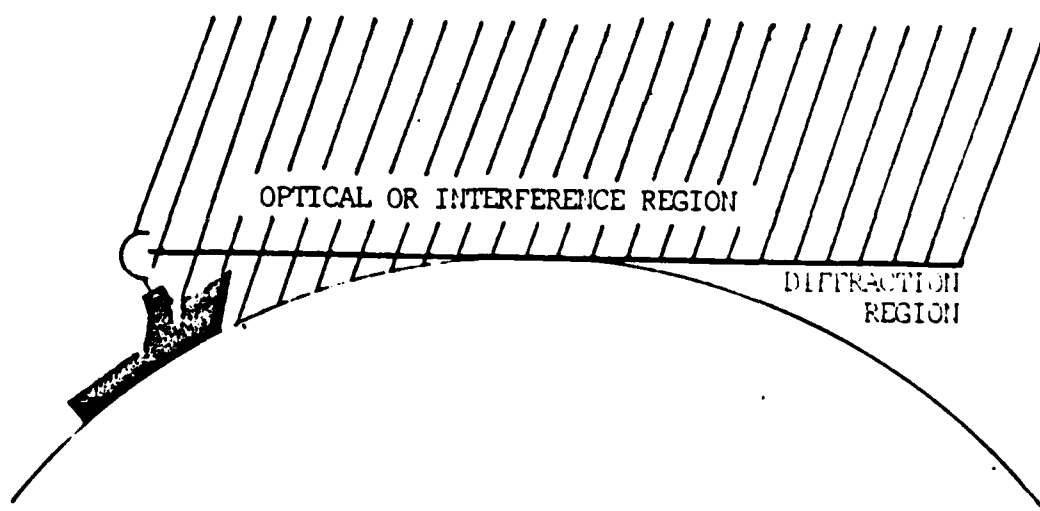


Figure 1. The Optical and Diffraction Regions

1. The Optical Region

Within the optical region, radar energy travels with spherical spreading generally in accord with the free space equation. When targets or radar transmitters are located near a large smooth surface like the ocean a portion of the energy is reflected off that surface. For shallow incidence angles and with smooth seas, nearly 99 percent of the energy is reflected with 180 degrees of phase change. With surface roughness, due to wind, the magnitude of the reflected energy can decrease to about 15 percent of the incident energy (still with 180 degrees of phase difference). As the transmitter to target geometry changes, the relative lengths of the direct and reflected paths also change. The received signal at the target is the vector sum of both the direct and reflected energy which causes received power to vary from 6 dB above (signals in phase) to 20 dB below (signal 180 degrees out of phase) the free space values.

2. Diffraction Effect

Radar energy in the diffraction region is usually due to diffraction by the curvature of the earth or refraction by the earth's atmosphere. The relatively weak field resulting from diffraction, which is predicted by electromagnetic theory, is generally too small to be effective for radar detection. At ranges beyond the radar horizon, propagation is dominated by a mechanism called tropospheric

scatter or troposcatter. This process of wave scattering due to certain heterogeneities causes path loss values that are so high it is impossible for any known radar to successfully detect targets. [Ref. 3]

3. Refraction and Anomalous Propagation

Although radar waves travel in straight lines in free space, waves in the atmosphere are bent or refracted due to the variation of the velocity of propagation with altitude. The effect is to extend the distance of the radar horizon beyond that for straight-line propagation. See Figure 2. The classical method of accounting for refraction in computations is by replacing the actual earth of radius a with an equivalent earth of radius ka and by replacing the

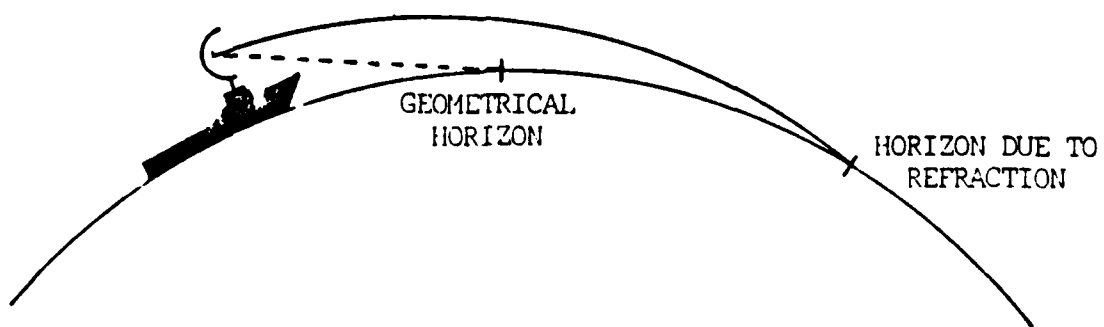


Figure 2. Horizon Extension Due to Refraction

actual atmosphere by a homogeneous atmosphere in which radar waves propagate in straight lines rather than curved lines.

[Ref. 4:p. 449] For standard atmospheric conditions the value of k used is $4/3$. The distance to the radar horizon can be shown to be approximately:

$$d = \sqrt{2 k a h} \quad \text{or} \\ d(\text{nautical miles}) = 1.064 \sqrt{k h(\text{ft})} \quad (10)$$

where h is the antenna height.

The most dramatic effects of refraction occur when the gradient of the index of refraction is sufficient to allow initially horizontal rays to be bent to very nearly follow the curvature of the earth. This condition is known as superrefraction, and such rays are said to be trapped. Rays normally can be trapped only if they originate within a layer of such conditions called a duct. Surface ducts extend upward from the surface to a height of a few hundred feet and on rare occasions up to one thousand feet. In the duct rays are bent down toward the ocean until a reflection occurs. The upward reflected ray is then gradually bent downward again until it again reflects from the surface. See Figure 3. A duct can be compared to a leaky waveguide; some fraction of the energy traveling within does escape. Generally energy coupled within a duct has an elevation angle to the duct of less than one degree and probably less than one-half degree [Ref. 5:p. 226]. These anomalous propagation conditions occur for k values greater than two.

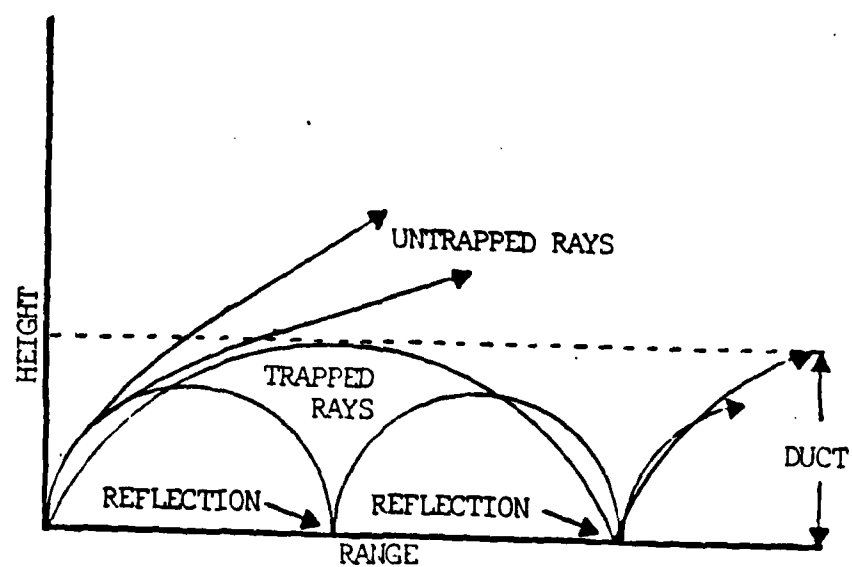


Figure 3. Radar Energy Propagation in Surface-based Duct

The ducting conditions restrict the spherical spreading of energy resulting in both extended ranges for energy trapped within the duct and reduced energy, or radar holes, outside the duct. Because the wave is trapped within the duct, vertical spreading of the wavefront is prevented. Since the wave is spreading in only one dimension rather than two, the average rate of power density decrease is reduced to $1/R$ (vice $1/R^2$ for the free space model). [Ref. 5:p. 227] Therefore a target located in or near a surface duct may be detected at a range beyond the normal free space detection range as well as below the radar horizon.

Figure 4 illustrates a typical one-way signal loss versus range profile demonstrating interference effects in the optical region and increased losses in the diffraction and troposcatter regions.

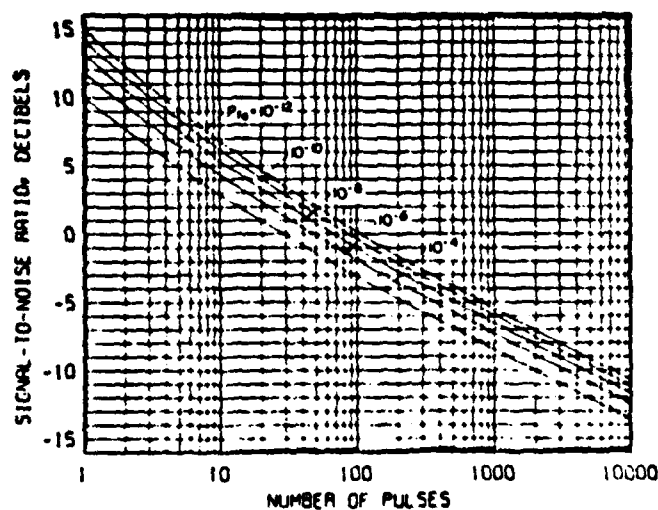


Figure 4. Required Signal-to-Noise Ratio for Detection with Noncoherent Integration of Pulses; Square-Law Detector, Swerling Case 3 Fluctuation, $P_d=0.50$ [Ref. 7]

The radar loss module of the IREPS computer package can be used to predict duct propagation for specified refractive index profiles. (For more details, consult Reference 3.)

D. DETECTION MODEL

When a radar target return signal is present within a noise or jamming background, the probability of detection is a function of its visibility factor which is the degree to which the received signal-to-noise (S/N) ratio exceeds a radar-specific detection threshold. The relationship between the detection probability and this excess signal-to-noise quantity is a function of both an associated probability of false alarm (P_{fa})--the probability that noise alone will cause the threshold to be exceeded--and the assumed distribution functions for the level of the signal. For the latter the Swerling Case III model for scan-to-scan fluctuations is considered most appropriate for targets such as jet aircraft and missiles [Ref. 6:p. 276].

Detection probability on a scan is enhanced by the integration or combining of signals by either radar display persistence or other electronic means. The benefit of integration is primarily due to the reduction or smoothing of noise variation [Ref. 5:p. 42]. The effect is to lower the required visibility for target detection. See Figure 5.

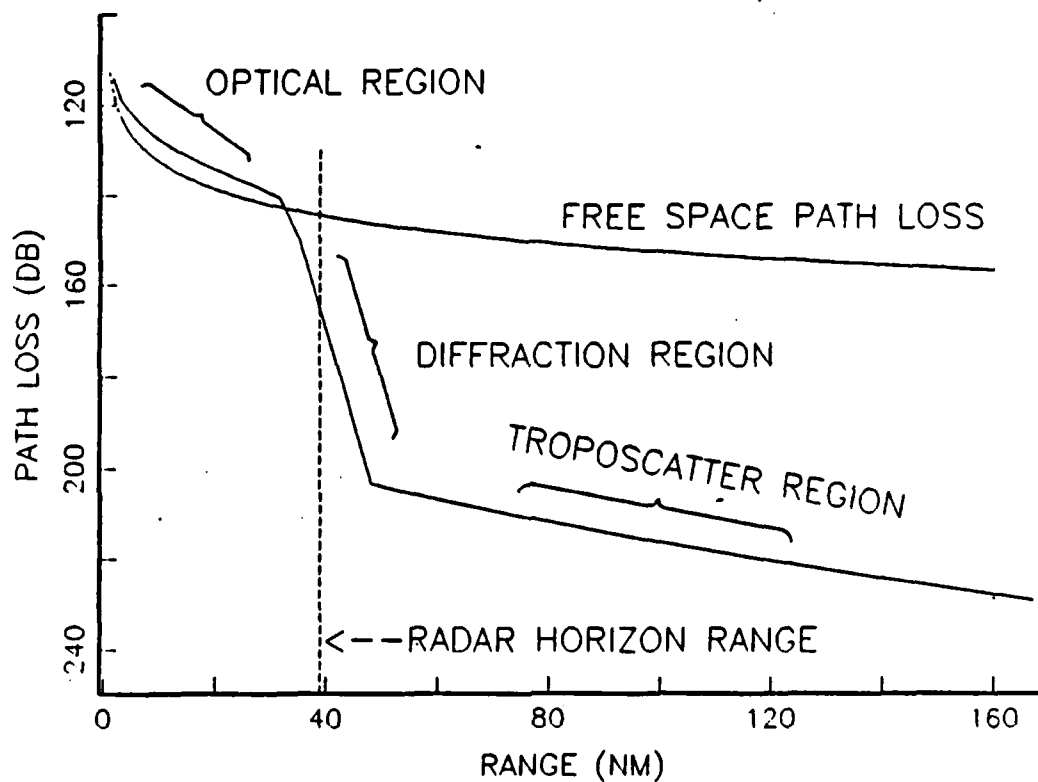


Figure 5. Path Loss for a 5000 MHz Transmitter at 90 feet and a Receiver at 500 feet for a Standard Atmosphere

A relationship between detection probability and excess signal-to-noise ratio was developed by the Johns Hopkins University Applied Physics Laboratory [Ref 7.]. The relationship is:

$$P_d = .5 [1 + \sin[(\text{excess } (S/J)) (\pi/18)]] \quad (11)$$

for $P_{fa} = 10^{-6}$

$$N = 10$$

and $-9 \leq S/J \leq 9$

to data obtained from Reference 7. (See Figure 6.)

E. OPERATOR FACTOR

Experts have postulated that when an operator becomes tired, bored or partially distracted, his efficiency is reduced and the probability of operator detection of a target is similarly diminished. This can be expressed in terms of an operator factor, P_o , which is defined as the probability that an operator will see a target signal that is detectable by an alert and perfect operator. It follows, therefore, that P , the probability that a scanned target is seen by the operator, can be expressed in equation form as:

$$P = P_o P_d \quad (12)$$

where P_o is the operator factor, and P_d is the previously derived probability of detection.

The nature of an operator factor is controversial. The operator factor often has been used to explain all differences between actual and theoretical performance. Although

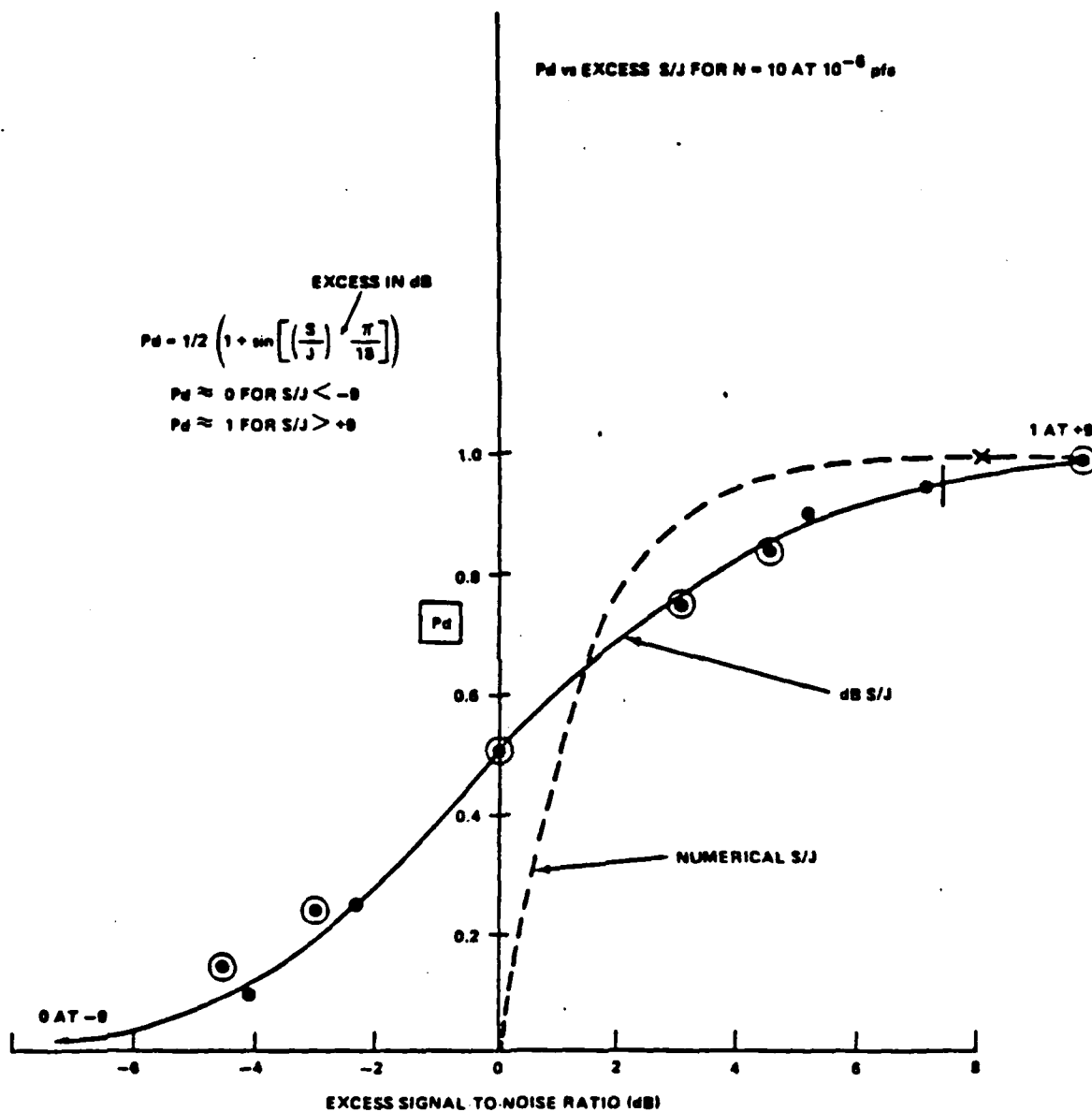


Figure 6. Probability of Detection versus Excess Signal-to-Noise Ratio for Probability of False Alarm of 10^{-6} and an Integration Factor of 10

originally proposed to be constant for a given operator or operator and experiment, research has shown operator performance to vary with signal strength, display brightness, radial and azimuthal position on the scope and numerous other factors [Ref. 8].

Scolnik and others lend support to a simple model of operator efficiency under good conditions. Scolnik's model uses the following relationship to determine the probability an operator will detect a target:

$$P = 0.7 (P_d)^2 \quad (13)$$

This can be interpreted as follows: An operator must first see a target signal on some scan and then see the target signal on the successive scan for detection to occur [Ref. 4:p. 253]. For this model, the operator factor for the first scan could be considered to be equal to 0.7, and that for the second scan, to be 1.

III. THE PROBLEM SOLUTION

A. PROGRAM OVERVIEW

The Fleet Anti-Ship Tactics Simulator (FASTS) is written using the HP 9000 Series 500 BASIC Language System for use on the HP 9000 Series Model 520 Computer. The program source code is contained in Appendix A. It employs the general structure and computational methods used in the Modified Jamming Aircraft and Radar Simulation (JARSM), a PL/I LANGUAGE program supported by the IBM 3033 system [Refs. 7 and 9]. Several modifications have been implemented to JARSM aircraft maneuvering and radar processing routines, the largest of which incorporates mechanisms for calculating radar path signal losses using modules from the IREPS program developed by NOSC.

FASTS simulates a many-on-many war-at-sea scenario involving ship-based early warning radars, strike aircraft and supporting radar jammers. It provides the tactics designer a testbed for evaluating strike tactics against a defensive radar network and for estimating the impact of certain environmental conditions on radar detection.

FASTS is implemented on an unbounded x-y coordinate grid and is controlled by a main routine clock which steps from time zero to a finish time provided by the user. A separate

parameter data file is appended automatically to the program for each scenario. Scenario data includes:

1. Radar parameters for up to 15 radar types
2. Radar locations for up to 15 radar systems
3. Jammer parameters for up to 15 jammer types
4. Aircraft radar cross section data for up to 15 aircraft
5. Aircraft location and flight profile data
6. Scenario time increment
7. Environmental data

Specific input parameters and format are defined in Appendix B.

There are four types of output available from FASTS: a time history of aircraft position, velocity, and probability of detection; a geographic plot of aircraft tracks and visibility; a plot of aircraft detectability versus time; and a simulation-based table of expected first-detection ranges for each aircraft and radar combination.

The program is written in structured format. Program flow is controlled via the Main Routine illustrated in Figure 7.

B. INITIALIZATION SUBROUTINE (INIT)

The most critical part of the FASTS program from the user's point of view is the data input. Subroutine INIT reads scenario parameters from the input data file (Appendix B refers)

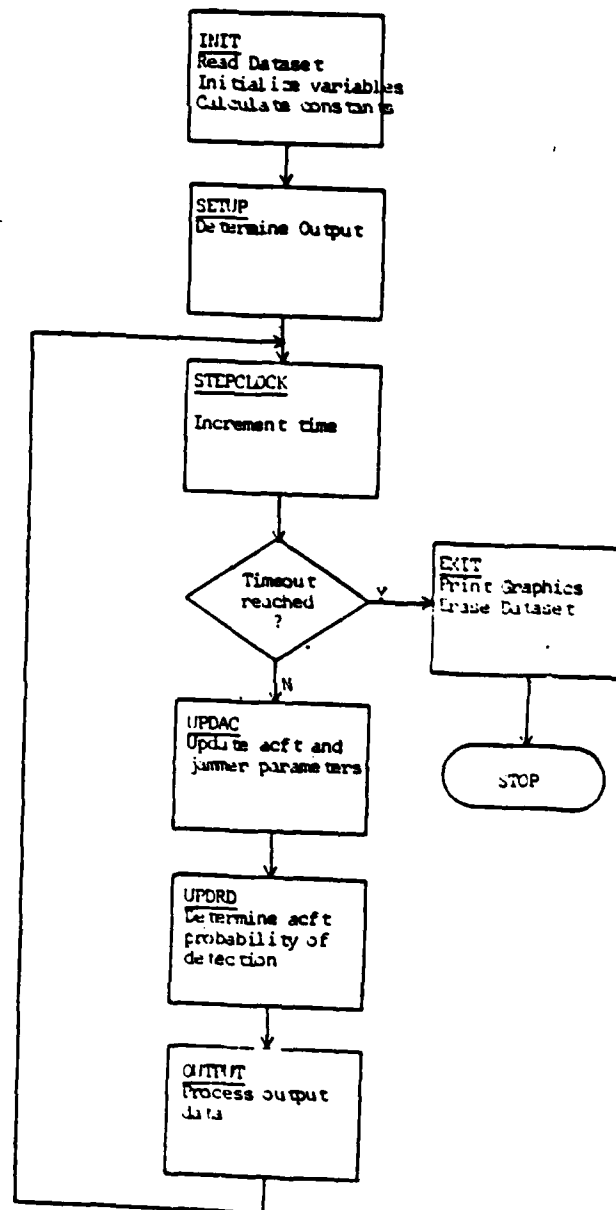


Figure 7. FASTS Main Routine

and processes them for program use. The following specific data elements are required:

1. Environmental parameters
 - a. Effective earth radius factor
 - b. Duct height (ft)
 - c. Wind velocity (knots)
2. Time parameters
 - a. Simulation time increment (sec)
 - b. Finish time (sec)
3. Radar type parameters
 - a. Effective radiated power (dB)
 - b. Frequency (MHz)
 - c. Antenna gain (dB)
 - d. Receiver figure of noise (dB)
 - e. Receiver noise bandwidth (MHz)
 - f. Receiver loss (dB)
 - g. Scan period (sec)
 - h. Antenna type
 - i. Azimuth bandwidth (degrees)
 - j. Elevation bandwidth (degrees)
 - k. Azimuth sidelobe gain (dB)
 - l. Antenna pattern
 - m. Antenna polarization
4. Radar site parameters
 - a. Type of radar
 - b. Location coordinates (x,y in nm)
 - c. Antenna altitude (ft)

5. Jammer type parameters
 - a. Effective radiated power (watts)
 - b. Bandwidth (MHz)
 - c. Frequency (MHz)
6. Aircraft type parameters--Radar aspect angle and associated radar cross section
7. Aircraft parameters
 - a. Initial location, altitude, heading and speed
 - b. Aircraft flight profile containing changes to each aircraft's position/velocity data and jammer status

The program time increment, D_t , is set to the minimum radar scanning interval (over all scan rates) if it is found to be less than the time increment read from the data file. Lastly frequently used constants for radar equation and jammer power equation calculations are computed for each radar and radar-jammer combination.

C. AIRCRAFT MODULE (UPDAC)

Subroutine UPDAC in FASTS controls the flight path for each aircraft in the scenario. The position, altitude and airspeed for each aircraft are updated at each clock increment. The aircraft is flown or controlled through the use of tactical commands issued from the scenario data file.

Seven different tactical commands are available:

1. JAM ON--Initiate jamming with a designated type of jammer
2. JAM OFF--Cease jamming with a designated type of jammer
3. CLIMB--Climb or dive to a specific altitude at a specific rate

4. TURN--Fly to a specific heading at a specific rate
5. HOME--Turn aircraft at each time iteration toward a specific radar site
6. FOLLOW--Maneuver with a specific aircraft

These instructions are stored and executed sequentially according to their initiation times. Due to the discrete time intervals of the simulation, the aircraft flight path is constant between update points. Thus, its flight path consists of a sequence of straight line segments. If the velocity of an aircraft is reduced to zero knots, it is removed from the simulation. This feature can be used to terminate aircraft tracking before the end of the simulation. Aircraft velocity is automatically set to zero whenever its velocity decreases to less than ten knots or its time-to-close the target of a HOME command is less than the simulation time increment.

The FOLLOW command was implemented as a convenience to enable aircraft to proceed in the company of another without having to repeat all maneuvering commands of the flight leader. This command is particularly useful in modeling missiles since missiles must remain co-positioned with the firing aircraft until launch. When an aircraft FOLLOW command is executed, all other maneuvering commands are cancelled. On execution of a subsequent maneuvering command, the FOLLOW command is cancelled and the aircraft retains the current position and velocity parameters.

Each aircraft in the simulation is capable of employing jammers which are turned on and off using profile commands. All jammers are initially off. A limitation of the program is that each aircraft may carry only one jammer of each type. Use of multiple jammers with the same parameters can be accomplished by defining different type jammers with identical specifications when building the data file. The flow diagram for Subroutine UPDAC is contained in Figure 8.

D. RADAR MODULE (UPDRD)

The radar subroutine is the heart of the FASTS program--all other program modules support it by either providing data inputs or processing its solutions for output. The subroutine evaluates aircraft position and aspect at each time interval and determines signal visibility. Logic flow is illustrated in Figure 9. The model considers antenna position, radar beam shape, atmospheric effects on attenuation and propagation, and relative position and power of each of the radar jammers.

Parameters for up to fifteen radar types are entered with the initial data file. Up to fifteen radar systems, with parameters of one of the radar types, may be fixed at any location or altitude on the x-y position grid. Co-location of radars is permitted. All radars radiate throughout the simulation; parameters and positions are held constant. Each antenna scans in a clockwise direction according to its input scan rate starting at the zero degree position.

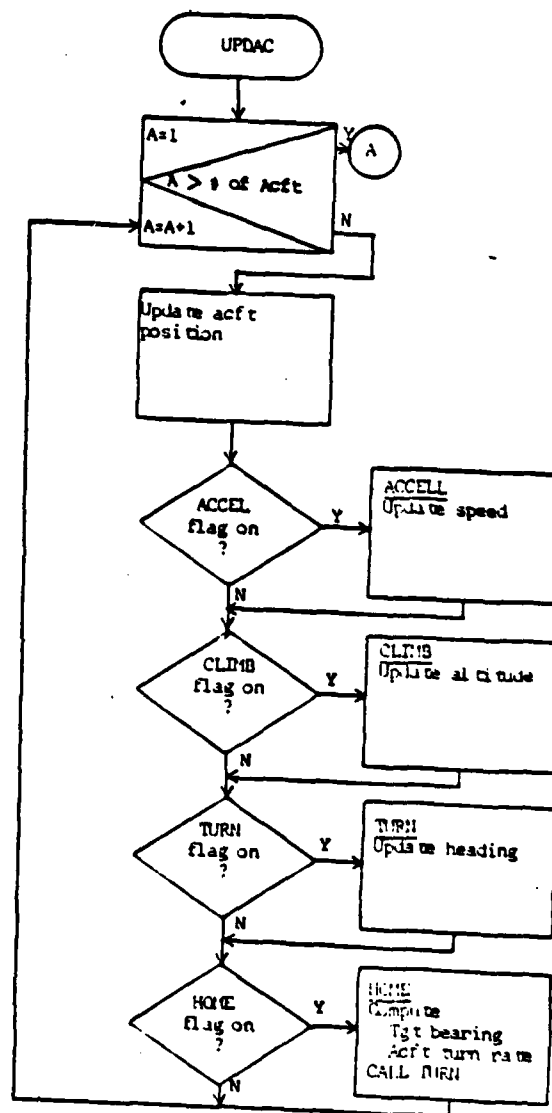


Figure 8a. Subroutine UPDAC

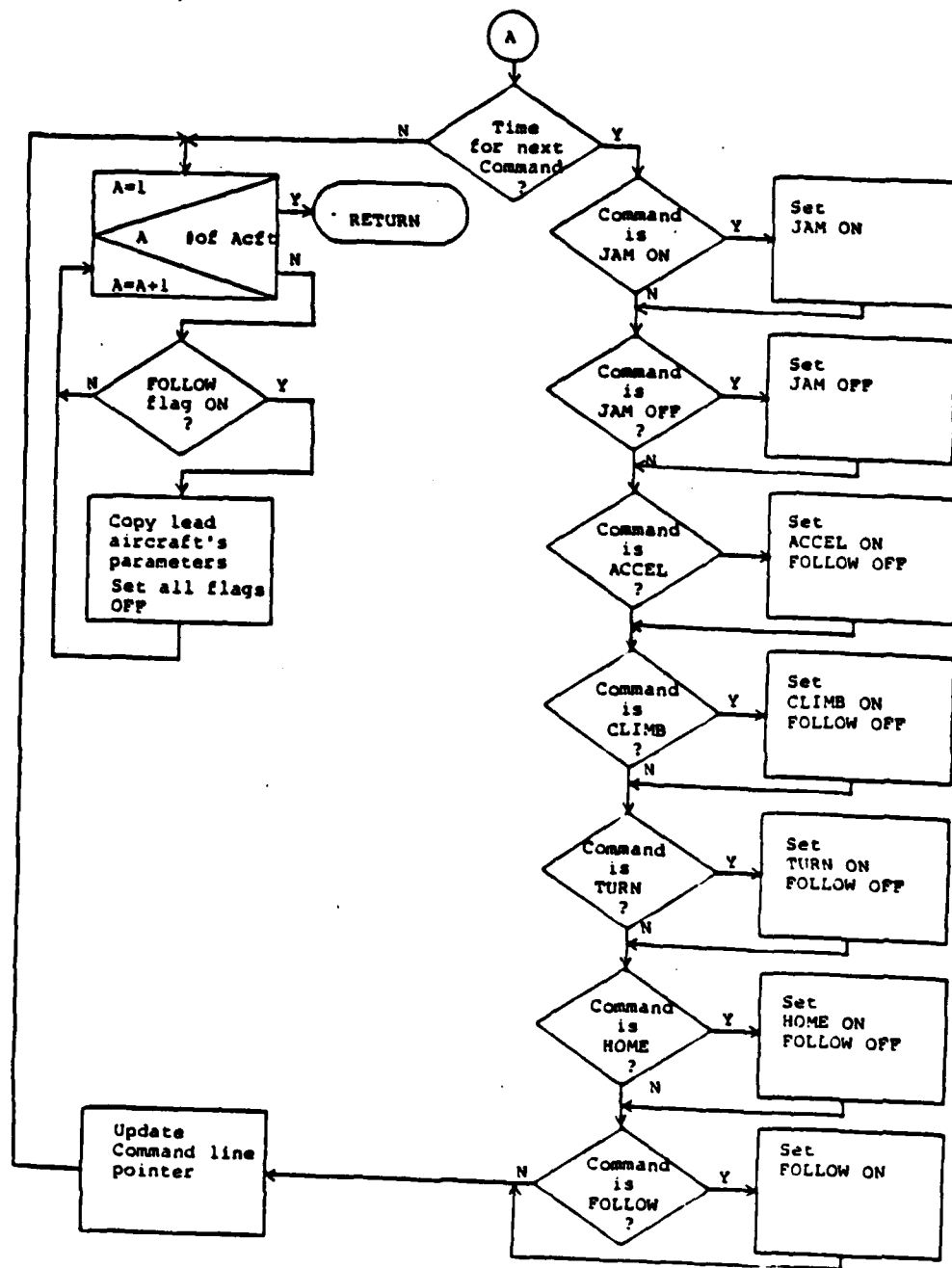


Figure 8b. Subroutine UPDAC (Cont'd)

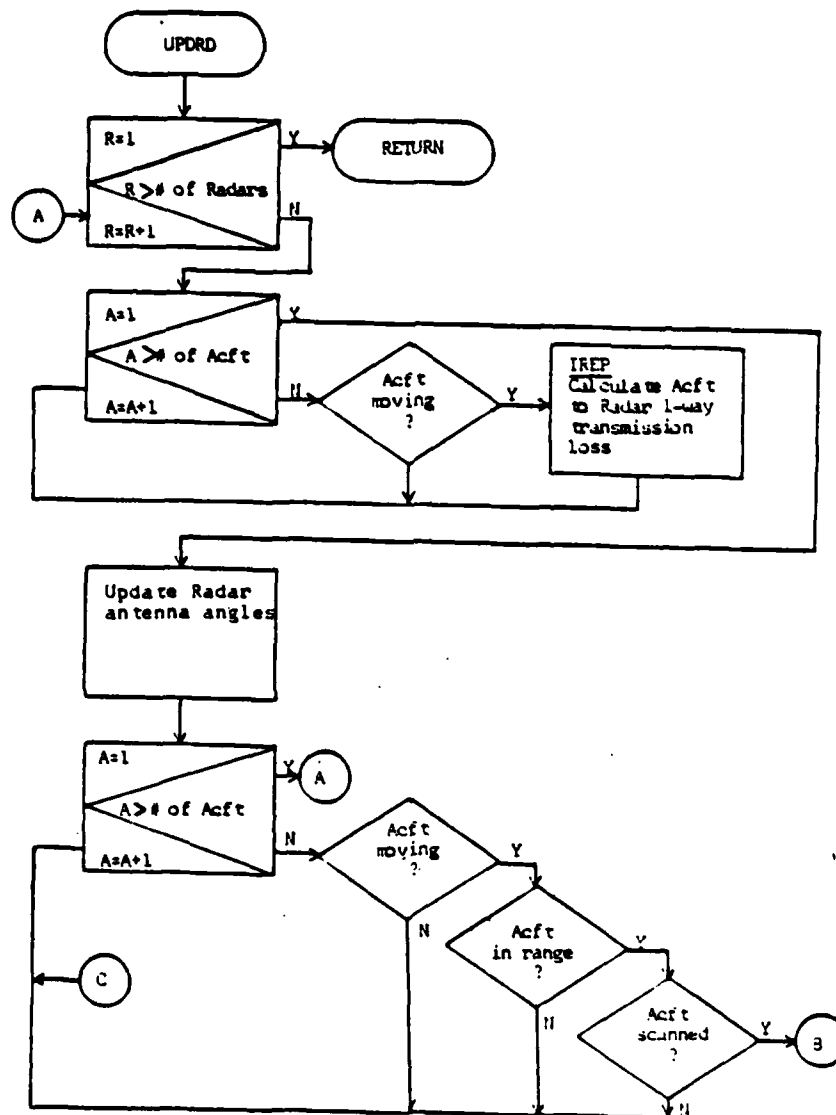


Figure 9a. Subroutine UPDRD

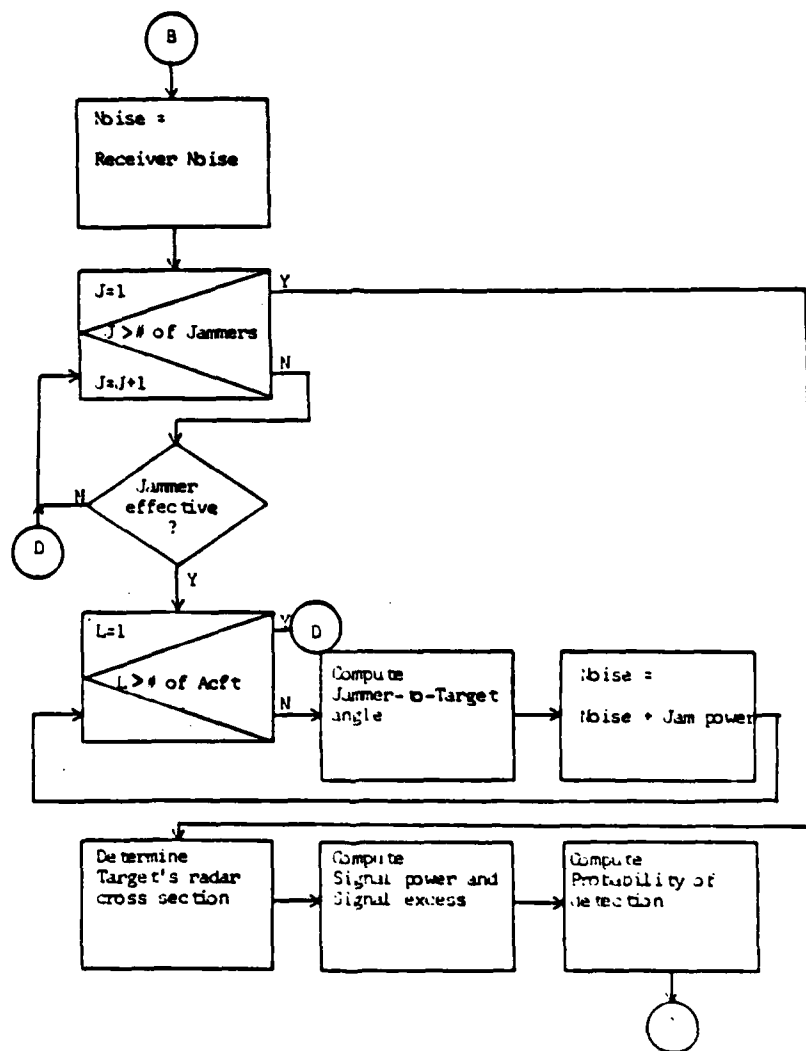


Figure 9b. Subroutine UPDRD (Cont'd)

Subroutine UPDRD evaluates detection probabilities considering each radar in turn.

1. Path Losses

One-way radar signal path losses are calculated between the site and each target using subroutine IREP. See Figure 10. The subroutine returns a value of the path loss obtained by dividing the loss-versus-range curve, Figure 4, into four sections and applying the appropriate formulas for each section. The first section extends from the radar site to the last range in the optical region where the direct and reflected waves are exactly in phase (RPEAK); the second, to the physical end of the optical region (OPMAX); the third, to the range at which the radar field attenuation becomes dominated by single mode diffraction and tropospheric scattering (DMIN); and the fourth section lies beyond.

Within the optical region, a spherical spreading wave model is used. Multipath effects caused by wave reflections off of a wind roughened surface and losses due to antenna vertical beam pattern are computed. At RPEAK, signal path losses are calculated to the maximum envelope of the interference null peaks. At ranges within the intermediate region between OPMAX and DMIN, loss is computed by linear interpolation. Beyond DMIN diffraction and troposcatter losses are calculated directly.

The FASTS subroutine IREP duplicates the loss module of the IREP Revision 2.2 program as closely as possible to

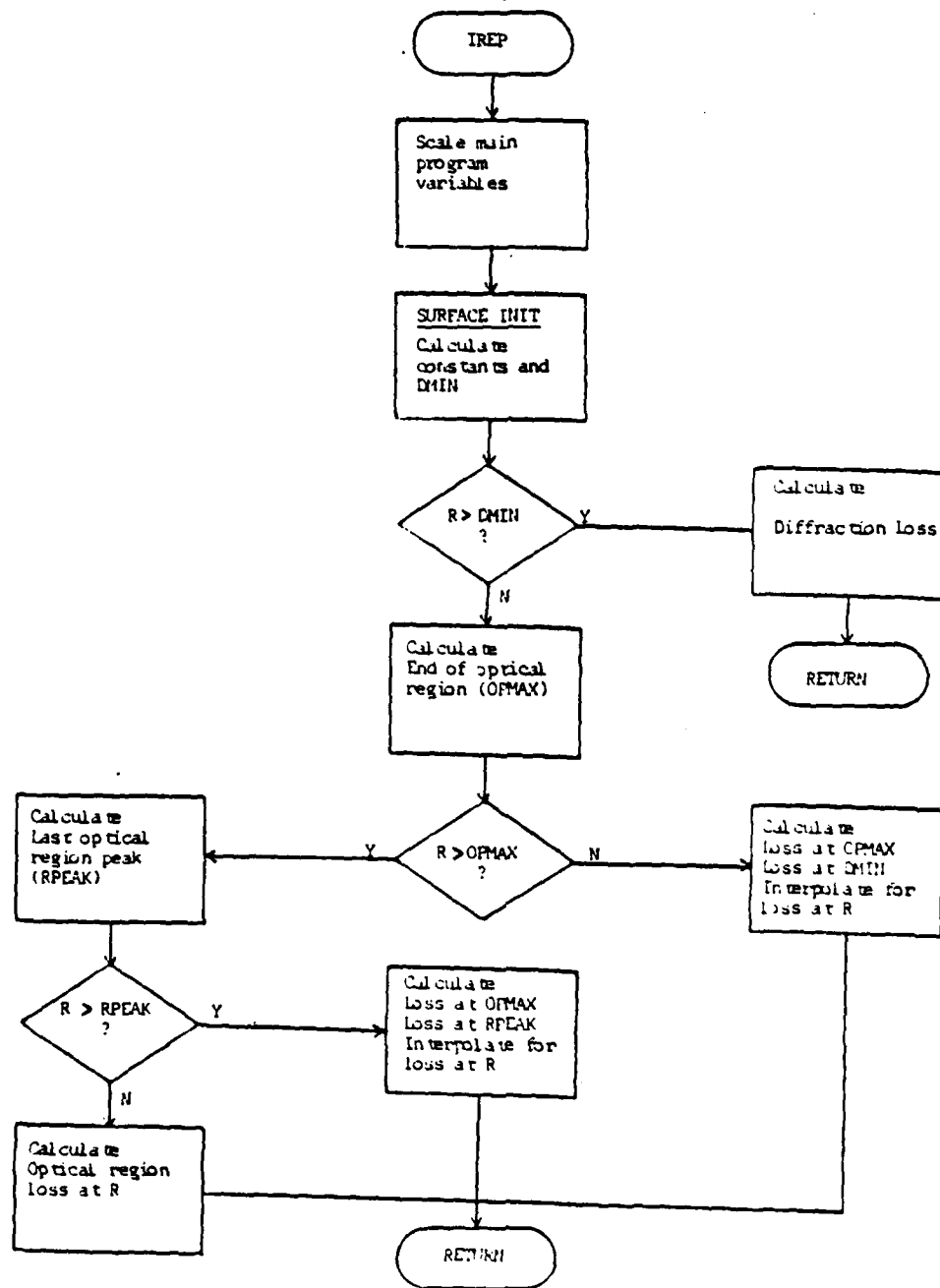


Figure 10. Subroutine IREP

permit future updating or modification. Variable names have been modified only to enable structural dovetailing with subroutine UPDRD and to prevent duplication of variable names. The one-way signal loss calculated by the IREPS program contains the radar equation factor for the antenna capture area, A_c , for an antenna of unity gain. Since the antenna capture area was already incorporated in the radar and jamming equations computed in subroutine IREP, the quantity:

$$A_c = \frac{\lambda^2}{4\pi} = \frac{c^2}{4\pi f^2}$$

was factored out of the IREP loss figure.

2. Noise Power

Noise power coupled into each receiver is computed by summing antenna thermal noise power and the noise power received from all aircraft jammers. Thermal noise power is computed as follows:

$$P_{no} = k T B_n F_n$$

where $k = 1.38E-23$ watt-sec/ $^{\circ}$ K (Boltzman's constant)

$$T = 290^{\circ} K$$

$$B_n = \text{Receiver noise bandwidth (Hz)}$$

$$F_n = \text{Receiver noise figure}$$

The jamming power constants, (Jampwr) are computed in subroutine INIT and are equivalent to the quantity contained in the unbracketed portion of Equation (9). A polarization loss factor of two is assumed for all jammers. Power transmitted by each jammer is attenuated by the one-way IREP

loss figure and the sidelobe loss based on the angular displacement of the target aircraft from the jammer. FASTS contains methods, developed for JARSM, which compute the sidelobe loss for two general azimuth pattern shapes:

$$\left[\sin(x) / x \right]^2 \quad \text{and} \quad \left[\frac{\pi}{2} \frac{\cos(x)}{\pi/2 - x^2} \right]^2$$

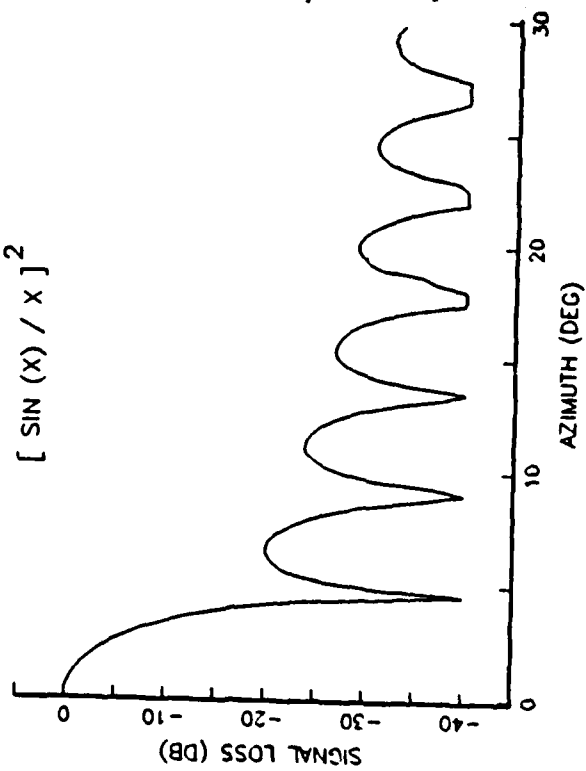
where x is the angle of displacement of the signal from the antenna axis in radians. These general forms are adjusted using the radar azimuth beamwidth and the level of the first sidelobe to approximate real antenna patterns. Figure 11 illustrates signal loss as a function of angular displacement for both antenna pattern forms.

3. Signal Power

The constant $Rdreqn$ is computed in the INIT subroutine to represent the combined value of all radar equation factors excepting radar cross section, σ (meter²), and the transmission loss factor. (Refer to Equation (8).) These additional quantities are position and aspect dependent and, therefore, are recomputed on each pass through subroutine UPDRD. The radar cross section is calculated by interpolation using the aircraft/radar aspect angle to enter a table of radar cross section values input via the data file. Since by reciprocity, the path from target to radar is the same as from radar to target, signal transmission loss is computed by doubling the one-way IREP loss figure.

TYPE 1

$$\left[\frac{\sin(x)}{x} \right]^2$$



TYPE 2

$$\left[\frac{\pi}{2} \frac{\cos(x)}{(\frac{\pi^2}{2}) - x^2} \right]^2$$

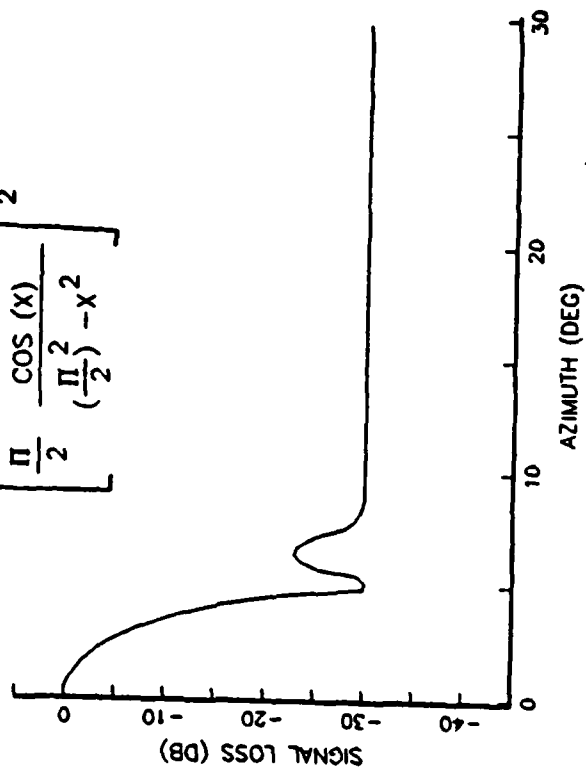


Figure 11. Radar Azimuth Antenna Patterns,
 Four Degree Beamwidth

4. Probability of Detection

Computation of the probability of detection for each aircraft/radar pair is made at each time increment. If the program determines that a radar has not scanned a particular aircraft, the associated probability is set to zero. Recall that the time increment can be no greater than the minimum radar scanning interval, and so it is quite possible to have incremental periods wherein the antenna axis of a radar does not cross all targets. If the aircraft is scanned by the radar, Equation (11) is used to determine the probability of detection based on the excess signal-to-noise ratio observed at the radar. The determination of the excess S/J ratio is made using the computed values for signal and noise power. The excess S/J ratio may be further reduced by a radar-specific visibility factor which shifts the value of the detection threshold to a value above unity. Figure 5 illustrates the visibility factor requirements for a representative radar system to achieve a 0.5 probability of detection. Note that the visibility factor is also a function of the selected probability of false alarm and the level of pulse integration. See Reference 7 for additional background.

E. PROGRAM OUTPUT

The subroutine Output processes simulation data at each iteration for direct output or for summary computations to be performed at the end of the simulation. Logic flow

diagrams for the subroutine are contained in Figure 12.

User selection of program output is made via interactive keyboard entry. Additionally the user is able to enter an output start time which determines the simulation time for the beginning of all output data displays and computations.

Four output formats are available. All output products can be printed or displayed on the CRT.

1. Data

Simulation data is printed for each aircraft following each time step iteration. Aircraft position coordinates, altitude, heading, speed, and radar detection probabilities can be sent to the CRT display or the system printer. The 80-column format of these displays limits output to simulations with four or fewer radar systems. The data output format is illustrated in Figure 13.

2. X-Y Plot

The X-Y Plot output selection displays a coordinate mapping of radar sites and aircraft positions throughout the simulation. The user selects plot coverage by entering coordinates for right, left, top, and bottom display boundaries. Aircraft movement tracks are displayed by solid or dotted lines reflecting susceptibility to detection by a selected radar system: A dotted line indicates a probability of detection less than 0.5; a solid line shows this threshold is met or exceeded. Normally all aircraft tracks are displayed in

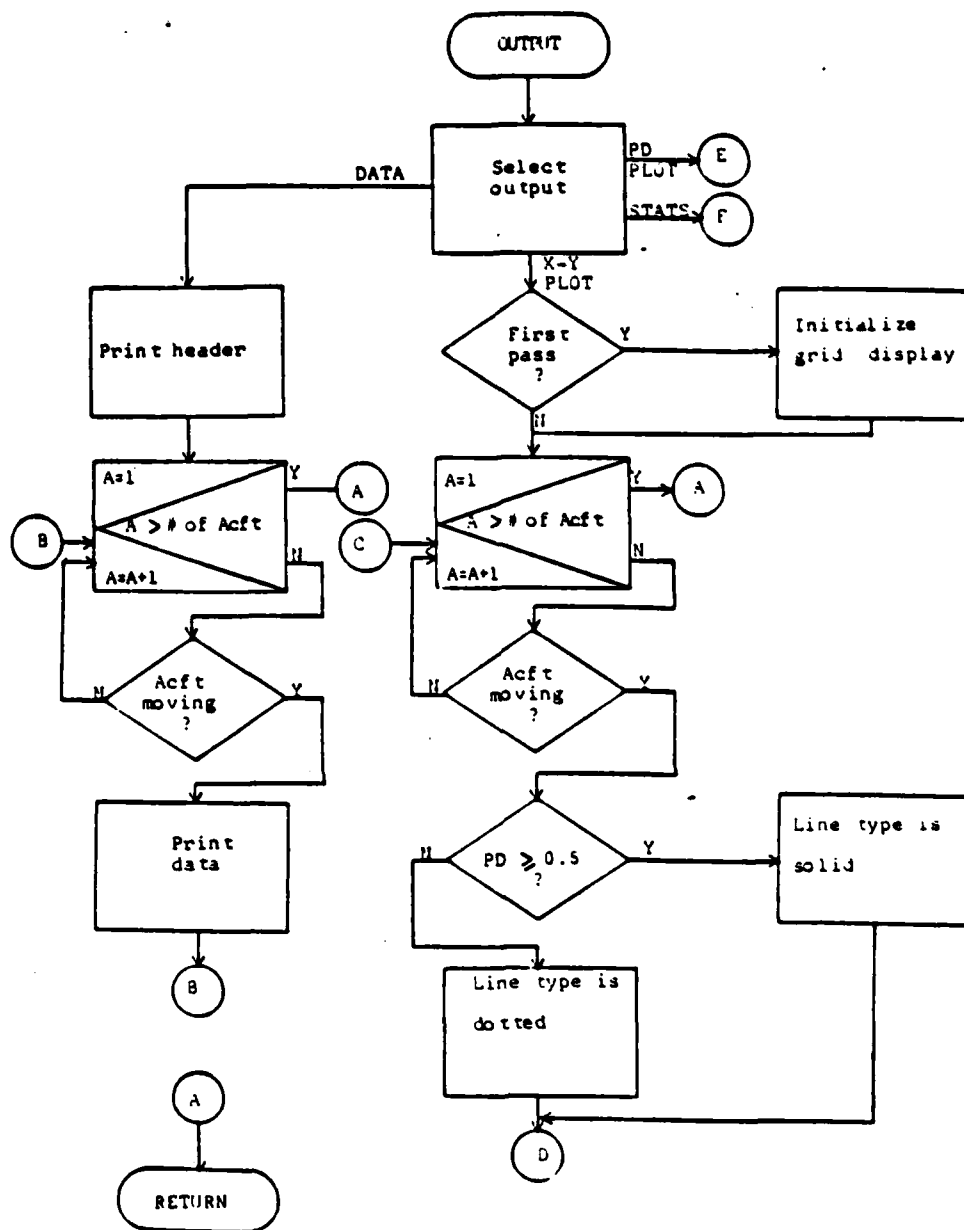


Figure 12a. Subroutine Output

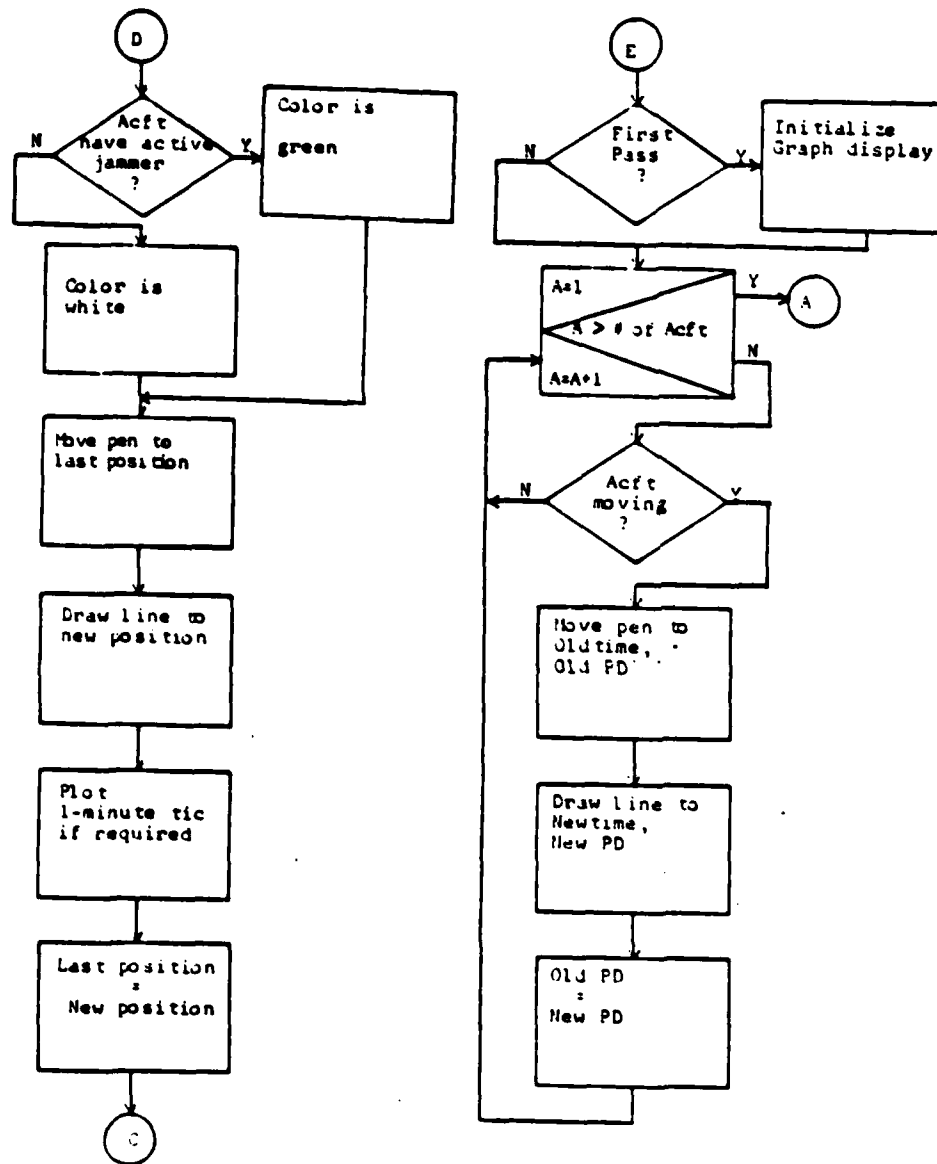


Figure 12b. Subroutine Output (Cont'd)

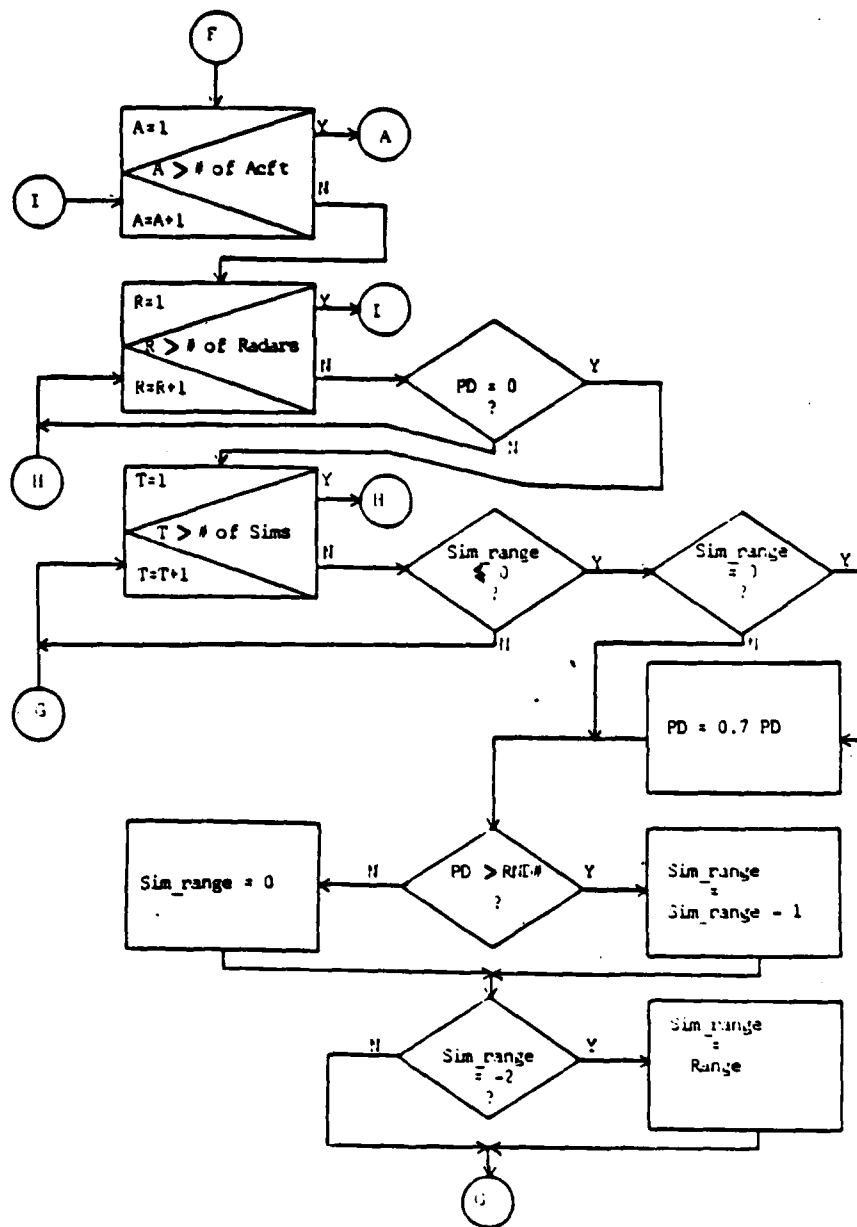


Figure 12c. Subroutine Output (Cont'd)

FASTS DATA OUTPUT				DATASET: SAMPLE				
ACFT	TIME	DX	DY	ALT	HEADG	SPEED	RADAR 1	RADAR 2
1	110.0	52.7	71.0	5000.0	190.0	500.0	.9150	1.0000
2	110.0	52.7	71.0	5000.0	190.0	500.0	0.0000	.3923
1	115.0	51.8	71.0	5000.0	190.0	500.0	.9235	1.0000
2	115.0	51.8	71.0	5000.0	190.0	500.0	0.0000	1.0000
1	120.0	51.0	71.0	5000.0	190.0	500.0	.9278	1.0000
2	120.0	51.0	71.0	5000.0	190.0	500.0	0.0000	1.0000

Figure 13. FASTS Data Output for Three Time Steps

white. Tracks for aircraft with jammers that are active against the selected radar are plotted in magenta. A sample of the X-Y Plot format is illustrated in Figure 14.

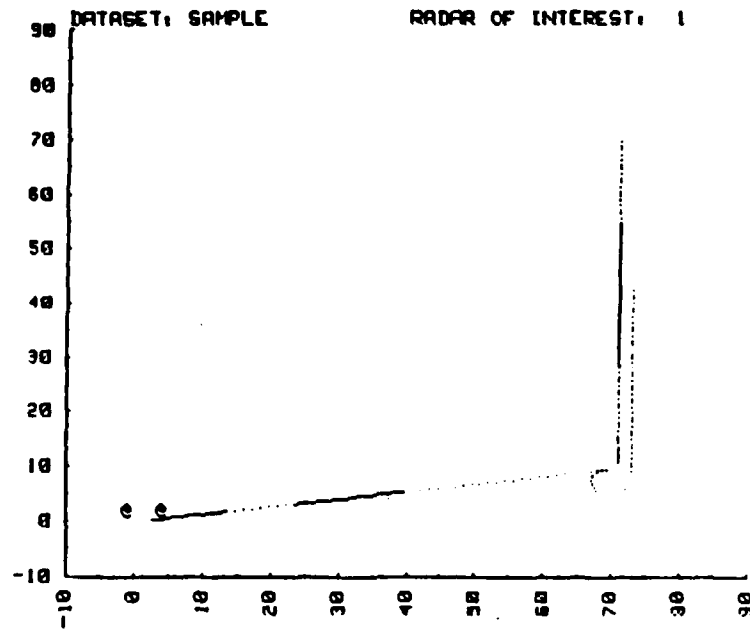


Figure 14. FASTS X-Y Plot Output

3. Probability of Detection per Scan Plot

The probability of detection per scan, P_d , for each aircraft by a selected radar is plotted against simulation time as depicted in Figure 15. The values for P_d , bounded by 0 and 1, are depicted on an unlabeled linear scale for each aircraft. The 0.5 probability of detection threshold reference is indicated by a dotted line for each aircraft. This plot

highlights time segments of high, low, or changing aircraft vulnerability to detection and permits comparative analysis between different aircraft and flight profiles. The user is cautioned not to interpret this to be a depiction of cumulative probabilities.

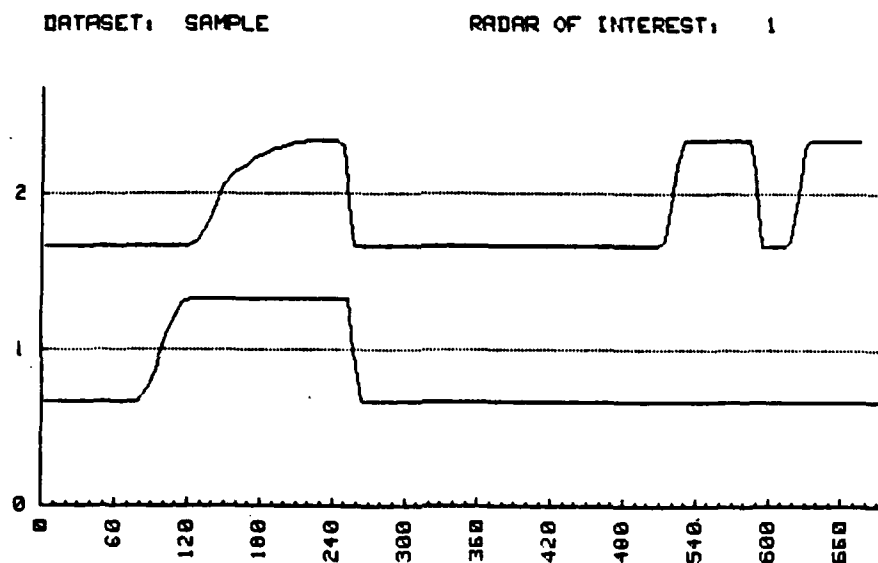


Figure 15. FASTS Probability of
Detection per Scan
Plot Output

4. First Detection Statistics

An estimate of the range of the first operator detection for each aircraft by each radar is made using statistical simulation and modeling of operator performance.

Throughout the program, fifty parallel detection simulations are maintained. At each iteration, if an aircraft is scanned, a random number, distributed uniformly on the interval (0,1), is drawn to support each of the fifty simulations. Using Equation (13), a detection is said to occur if the probabilities of detection on two successive scans exceed the random number drawn for each event. The probability of detection for the first of these two scans is reduced by thirty percent to compensate for the unalerted operator. If an operator detection is obtained, the range is recorded for later statistical computations. After the finish time has been reached, the fifty ranges are processed by subroutine Output-stats. See Figure 16. The ranges are sorted, and mean, standard deviation, and quantile statistics are computed over all simulations which experienced a detection. The percentage of simulations in which the aircraft was detected is computed as an estimator of an aircraft's probability of detection for the mission.

All statistics represent simulation events occurring after the user entered start time. The feature of start time selection allows the user to determine, for example, the range for the first operator detection of an aircraft following its descent to a low altitude where masking by the radar horizon occurs. In any case, first operator detection statistics can lose meaning if the aircraft is already detectable when the statistical computations are commenced.

A sample output for First-Detection Statistics is illustrated in Figure 17.

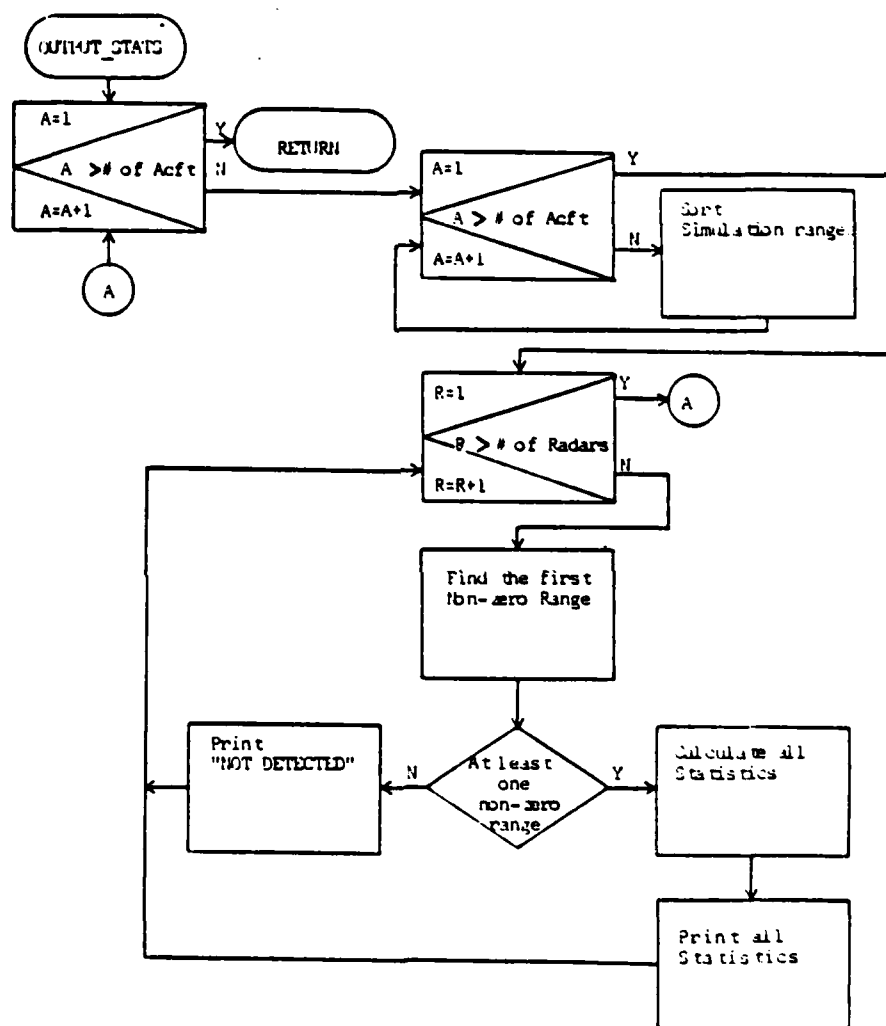


Figure 16. Subroutine Output-stats

FASTS STATISTICS OUTPUT
START TIME: 400

DATASET: SAMPLE

AIRCRAFT 1		DETECTION RANGE STATISTICS							
RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET			
1	NOT DET	NOT DET	NOT DET	NOT DET	NOT DET	0			
2	NOT DET	NOT DET	NOT DET	NOT DET	NOT DET	0			

AIRCRAFT 2		DETECTION RANGE STATISTICS							
RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET			
1	38.140	.945	37.140	38.390	38.390	1.000			
2	42.330	1.213	41.568	42.818	42.818	1.000			

Figure 17. FASTS Statistics Output

IV. FASTS VERIFICATION

Considerable program verification was accomplished during the creation of the program. The proper operation of the data initialization, aircraft maneuvering, radar scanning and input/output features was confirmed as each module was assembled into the program. Variable tracing techniques and analysis of output data and graphics were used. To determine if FASTS was operating as intended, several aircraft/jammer flight profiles were simulated for which the results were easily predicted.

Verification of the radar simulation was accomplished by confirming proper operation of the environmental signal loss routine and analysis of the model output data with respect to aircraft detection at the radar horizon, jammer burnthrough ranges, and detection ranges for aircraft in a standoff jamming environment.

A. LOSS COMPUTATION TEST

Values for one-way signal transmission losses were traced for aircraft opening a radar site at altitudes of 500, 1000, and 5000 feet and compared with IREPS Revision 2.2 Loss Display data. Parameters for the AN/SPS-10 radar system and standard day atmospheric conditions were employed. The signal loss data compared within 2 dB for all three cases over ranges up to 160 nautical miles.

B. RADAR HORIZON TEST

FASTS simulations were conducted in which aircraft flew outbound from a radar site at 100, 200, and 500 feet. Using standard day atmospheric conditions and an antenna height of 100 feet, the last ranges at which the radar visibility threshold was exceeded were noted and found to be in agreement with the predicted theoretical radar horizon. Data for the tests are presented in Table 1 and Figure 18.

TABLE I
RADAR HORIZON TEST RESULTS

	Altitude (ft)			
	100	200	500	1000
Predicted Range (nm)	24.6	29.7	39.8	51.1
Observed Range (nm)	25	28	37	47

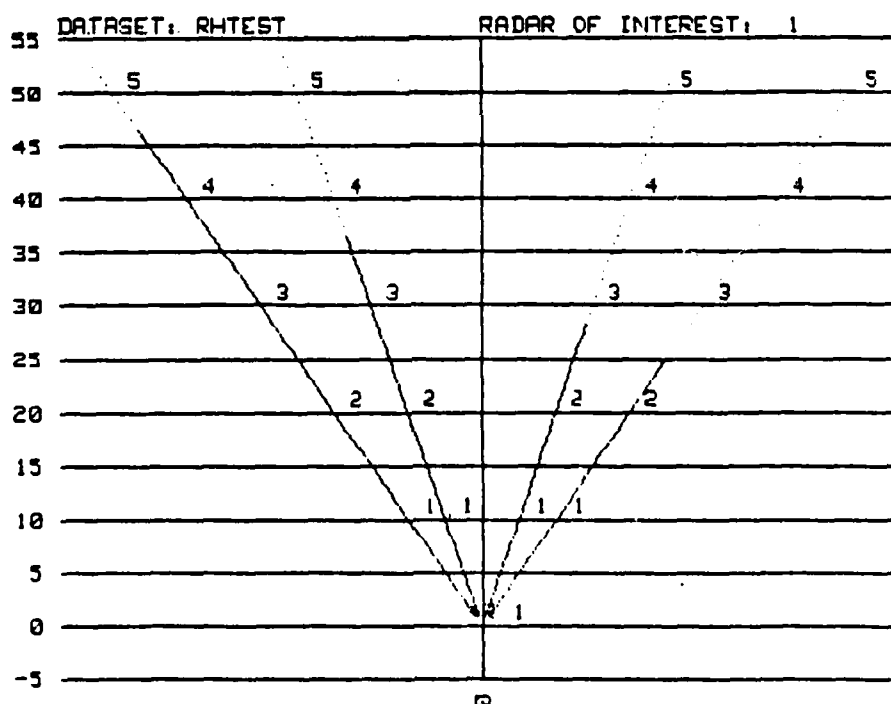


Figure 18. Radar Horizon Test

The deviation of the test results of up to eight percent from the predicted values are not considered to reflect any imprecision in the program. The radar horizon represents the end of the optical region beyond which the rate of signal attenuation shows a marked increase and, thus, is an upper bound approached by the ranges at which the returned power exceeds the radar's visibility threshold.

C. JAMMER SELF-SCREENING TEST

Two FASTS simulations were conducted in which aircraft carrying active jammers closed toward a radar site. The ranges at which the radar's visibility threshold was exceeded were compared with those predicted by equating the radar and jammer power equations (Equations (8) and (9)) and solving for range. The inherent assumptions for the equations of isotropic and non-reflected radiation were satisfied by a program modification setting the program variable for the pattern factor (FFAC) equal to unity. Results, presented in Table II, confirmed proper operation of noise power and detection probability computations.

D. STANDOFF JAMMER TESTS

1. Azimuth Test

Verification of the radar azimuthal antenna pattern modeling was accomplished through use of a multi-aircraft scenario. The jammer and twelve additional aircraft closed the target radar simultaneously from fifty nautical miles at

TABLE II
JAMMER SELF-SCREENING TEST RESULTS

	Simulation 1	Simulation 2
Predicted Range (nm)	17.03	35.26
Observed Range (nm)	17	35
Parameters:		
Pt (kw)	100	1000
Gt	10,000	10,000
Br (MHz)	0.5	0.1
Pj (kw)	0.8	14.0
Bj (MHz)	100	150
(m)	25	25

500 feet using one degree separation of inbound headings. The $(\sin x/x)^2$ azimuth antenna pattern--Type 1--with a four degree beamwidth and 20 dB loss in the first sidelobe was used. Figure 19 depicts the scenario and demonstrates the expected reduction of jammer protection afforded aircraft with increasing displacement from the jamming axis. Pattern nulls can also be discerned.

2. Range Test

This test was conducted to observe the effects of altitude, atmospheric ducting and jamming on the target range required to exceed the radar visibility threshold. An effective earth radius, k , of 3.92 and a duct height of 996 feet were used. In six simulations, targets flying at altitudes of 500 feet (in the duct) and 2000 feet (above the duct) closed a radar site. Jammer aircraft, when used, flew at 500 feet or 2000 feet, either with or directly above or below the target. The six simulations were repeated for standard day atmospheric conditions. The target observation ranges are presented in Table III.

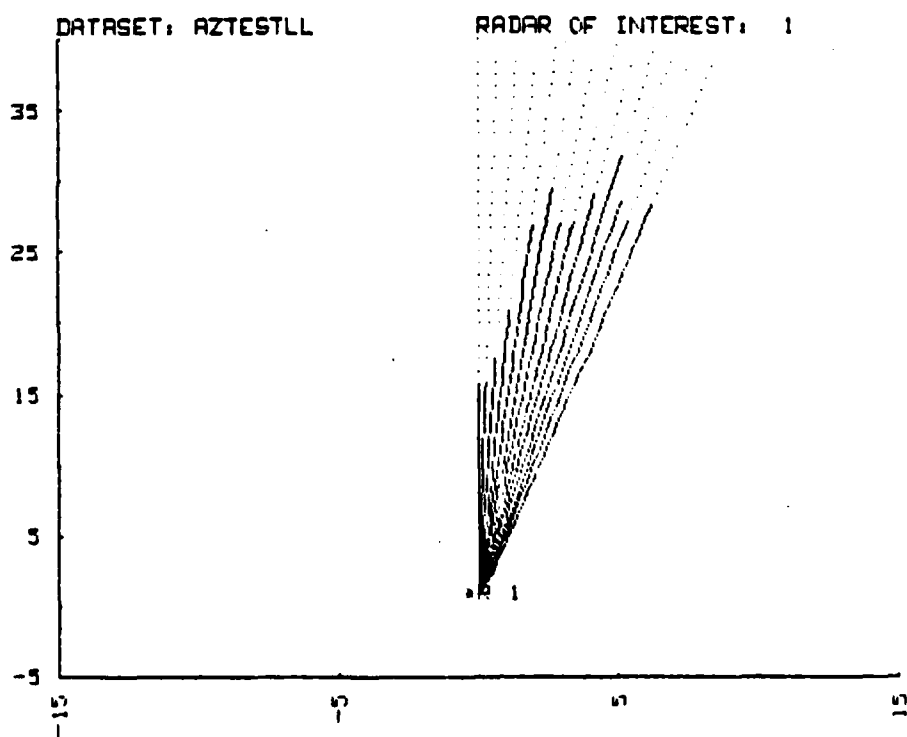


Figure 19. Standoff Jammer Test

TABLE III
RANGE TEST RESULTS

Target Altitude (ft)	Standard Day			Standard Day		
	None	Jammer Altitude 500 ft	2000 ft	None	Jammer Altitude 500 ft	2000 ft
500	34	17	15	>120	20	18
2000	62	55	28	93	46	29

Parameters:

Pt (kw)	100
Gt	10,000
Br (MHz)	0.5
Pj (kw)	0.8
Bj (MHz)	100
(m)	25

Without jamming and under standard day conditions, the targets were seen as they crossed their radar horizon ranges. Predictably, ducting extended the detection range for the low target and due to duct leakage effects, considerably extended the detection range for the target operating above the duct.

When jamming was employed, detection ranges were reduced in all cases.

The effect of locating the jammer within the duct is seen in an increased detection range (over that for nonducting conditions) for the target located within the duct which is caused by reduced transmission losses for both the radar and jammer signals. Reduced detection ranges for a target located above the duct are consistent with the increased jammer efficiency within the duct and the spherical propagation loss associated with the radar-to-target signal path.

When both the jammer and target are above the duct, detection ranges are shown to be nearly equal to those for standard day conditions, as expected, since spherical spreading laws are dominant.

Other verification tests are, no doubt, possible. However, these tests are sufficient to show that FASTS does perform accurately and consistently.

V. SAMPLE IMPLEMENTATION

An example of a tactical simulation is described in this chapter which includes a scenario definition, the initial tactical plan, the data file construction, a program execution outline and an analysis of the program output.

A. SCENARIO

In this example, FASTS is used to analyze an air strike against two ships located 300 nautical miles from base. The ships are defended by surface-to-air weapons, and so a standoff delivery of air-to-surface missiles (ASM's) is desired. Two ASM attack aircraft, one anti-radiation missile (ARM) aircraft, and a supporting tactical jammer aircraft are available.

The aircraft will proceed together toward the target at medium altitude (5000 feet) and descend to 1000 feet at 75 nautical miles from the target. At 50 nautical miles, the ASM aircraft split from the formation, turning 50 degrees right and left of the target bearing, and accelerate to attack speed. The ARM aircraft continues to close the target, fires his missile at 30 nautical miles, and retires. The jammer slows slightly, commences jamming, and establishes a figure-eight pattern at 30 nautical miles.

At 2 minutes and 35 seconds after the split, the first ASM aircraft turns left toward the ships, fires his missile

from 30 nautical miles at the rightmost ship, and turns to retreat. The second ASM aircraft turns right three minutes following the split, fires his missile from 30 nautical miles at the leftmost ship, and retires.

Near simultaneous impact of ASM's is desired; the ARM should arrive earlier to support the ASM's penetrating of the ships' radar defenses.

B. DATA FILE CONSTRUCTION

The data file is constructed as described in Appendix B. The listing is provided in Figure 20. Once constructed, the data file is easily modified to permit adjustment to the tactical scenario. The data file must be saved using the SAVE or RE-SAVE command in order to prevent loss of the file when the FASTS program is loaded.

C. PROGRAM EXECUTION

The source program is brought into the computer memory by entering the command LOAD "FASTS". On entering RUN, the program execution is begun, and the user is prompted to enter the data file name; the data file is retrieved and appended to the FASTS program. Following interactive queries to define the desired output form, the simulation is commenced.

The X-Y Plot output option is selected first and reviewed to verify the proper maneuvering geometry for the aircraft and proper radar positioning. Verification of the CLIMB and ACCEL commands is performed by reviewing the DATA


```

10 Dat: DATASET NAME
20 DATA WASI
30 I
40 IREPS K DUCT HT (FT) WIND
50 DATA 1.33, 0, 8
60 I
70 I NAC NJM NRD NACTYP NRD1TYP DT TFIN
80 DATA 7, 2, 2, 2, 2, 10, 1000
90 I
100 Rdr-dat: I
110 I RNTYP ROLAT ROLONG RDALT
120 DATA 1, 0, 0, 80 I RDR 1
130 DATA 2, 0, 5, 80 I RDR 2
140 I
150 I RDSCNTYP RDB1TYP RMAX1TYP RUZEROTYP
160 DATA 5, 0, 250, 0 I RDR 1
170 DATA 5, 1, 125, 0 I RDR 2
180 I
190 I
200 I RDERPTYP RDRFQ1TYP RRGANTYP RDRFNTYP RDNBW1TYP LOSSTYP
210 DATA 90, 1000, 40, 10, .5, 10 I RDR 1
220 DATA 102, 850, 35, 7, 0.1, 7 I RDR 2
230 DATA 98, 31
240 I
250 I
260 I RDAZBW1TYP RDAZSL1TYP ROELBW1TYP CSCSQ1TYP DT1TYP HPOLAR
270 DATA 4, -20, 4, 0, 1, 1 I RDR 1
280 DATA 3, -20, 7, 0, 1, 1 I RDR 2
290 DATA 3.5, -20, 4, 1, 1, 0
300 I

```

Figure 20a. Data File Listing

```

310 Jmdat:1
320 1 JMBW JMRP
330 DATA 100, 900
340 DATA 150, 14000
350 1
360 1
370 1 ALPHA RCS
380 DATA 0, 14
390 DATA 180, 14
400 DATA 9999, 00.0
410 1
420 DATA 0, -3
430 DATA 180, -3
440 DATA 9999, 0
450 1
460 Acdat:1
470 1 ACTYPE ACLAT ACLONG ACALT ACHDS ACVEL
480 DATA 1, 100, 0, 5000, 180, 360 1 JAMMER
490 DATA 1, 100, 0, 5000, 180, 360 1 SHOOTER(R)
500 DATA 1, 100, 0, 5000, 180, 360 1 SHOOTER(L)
510 DATA 1, 100, 0, 5000, 180, 360 1 SHOOTER(C)
520 DATA 2, 100, 0, 5000, 180, 360 1 MISSILE(R)
530 DATA 2, 100, 0, 5000, 180, 360 1 MISSILE(L)
540 DATA 2, 100, 0, 5000, 180, 360 1 MISSILE(C)
550 1

```

Figure 20b. Data File Listing (Cont'd)

560 I	TIME	CHANGE	X	Y
570 ACFT1				
580 DATA	1,	6,	3,	1
590 DATA	250,	4,	-100,	1000
600 DATA	500,	3,	-5,	300
610 DATA	500,	1,	1,	0
620 DATA	500,	1,	2,	0
630 DATA	740,	5,	-3,	181
640 DATA	860,	5,	3,	180
650 DATA	980,	5,	3,	045
660 DATA	9999			
670 I				
680 ACFT2				
690 DATA	1,	7,	1,	0
700 DATA	500,	3,	5,	420
710 DATA	500,	5,	3,	230
720 DATA	655,	6,	3,	1
730 DATA	740,	5,	-3,	360
740 DATA	9999			
750 I				
760 ACFT3				
770 DATA	1,	7,	1,	0
780 DATA	500,	3,	5,	420
790 DATA	500,	5,	-3,	130
800 DATA	680,	6,	3,	2
810 DATA	750,	5,	-3,	360
820 DATA	9999			
830 I				

Figure 20c. Data File Listing (Cont'd)

840 IACFT4				
850 DATA 1,	7,	1,	0	I FOLLOW JAMMER
860 DATA 500,	3,	5,	360	I MAINTAIN 360 KTS
870 DATA 700,	5,	-3,	360	I TURN AFTER SHOT
880 DATA 9999				
890 I				
900 IACFT5				
910 DATA 1,	7,	2,	0	I FOLLOW SHOOTER(R)
920 DATA 730,	6,	3,	1	I HOME TO RDR 1
930 DATA 730,	3,	50,	550	I ACCEL
940 DATA 730,	4,	-100,	50	I FALL TO 50 FT
950 DATA 9999				
960 I				
970 IACFT6				
980 DATA 1,	7,	3,	0	I FOLLOW SHOOTER(L)
990 DATA 740,	6,	3,	2	I HOME TO RDR 2
1000 DATA 740,	3,	50,	550	I ACCEL
1010 DATA 740,	4,	-100,	50	I FALL TO 50 FT
1020 DATA 9999				
1030 I				
1040 IACFT7				
1050 DATA 1,	7,	4,	0	I FOLLOW SHOOTER(C)
1060 DATA 700,	6,	3,	1	I HOME TO RDR 1
1070 DATA 700,	3,	50,	750	I ACCEL
1080 DATA 700,	4,	1000,	10000	I CLIMB TO 10000 FT
1090 DATA 9999				

Figure 20d. Data File Listing (Cont'd)

output information. If the simulation is seen to be operating properly, the X-Y Plot figure may be sent to the printer. Figures 21 through 24 represent plots of the strike for 100 and 50 mile ranges displaying visibility thresholds for each radar.

The program is run again, and the Probability of Detection Plot output is selected. Graphs are printed showing the probability of detection for each aircraft relative to each radar system. (See Figures 25 and 26.)

The first Detection Statistics output is obtained on the final run. The initiation time for the statistics compilation is chosen to be twenty seconds after the launch of the second ASM to allow both missiles to fall below their radar horizon altitudes. Figure 27 contains the statistics output for the missiles, i.e., aircraft 5, 6, and 7.

D. EVALUATION OF RESULTS

Analysis of the X-Y Plot and Probability of Detection per Scan Plot shows the strike group would almost certainly have been acquired by enemy radars and tracked from the radar horizon at 90 miles until they descended at 75 miles. Jamming protection after the formation split at 50 miles only provided 50 to 80 seconds of coverage for the ASM aircraft due to their increasing displacement from the jamming axis. The ASM aircraft should expect to be tracked continuously by both ships from this burnthrough point through weapon delivery and their outbound turn maneuver.

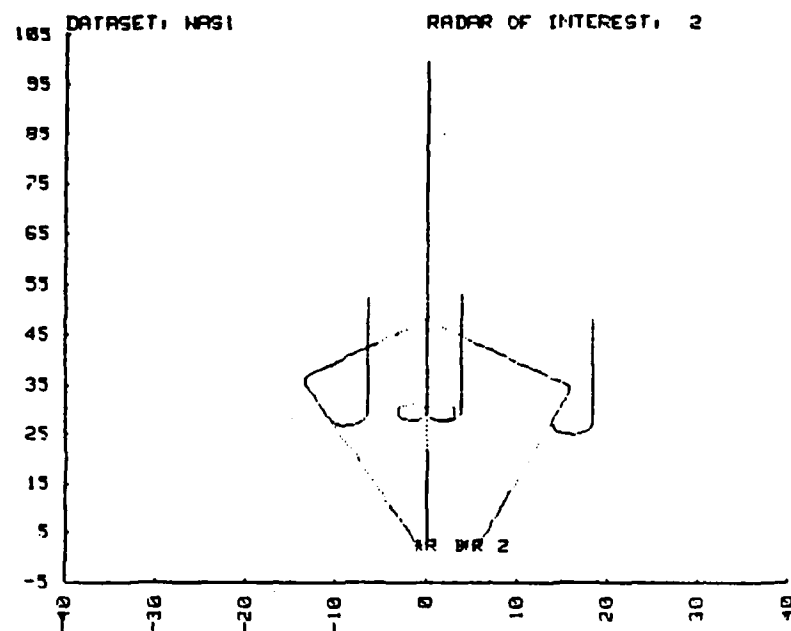


Figure 21. X-Y Plot for Radar 1; 105 nm Range

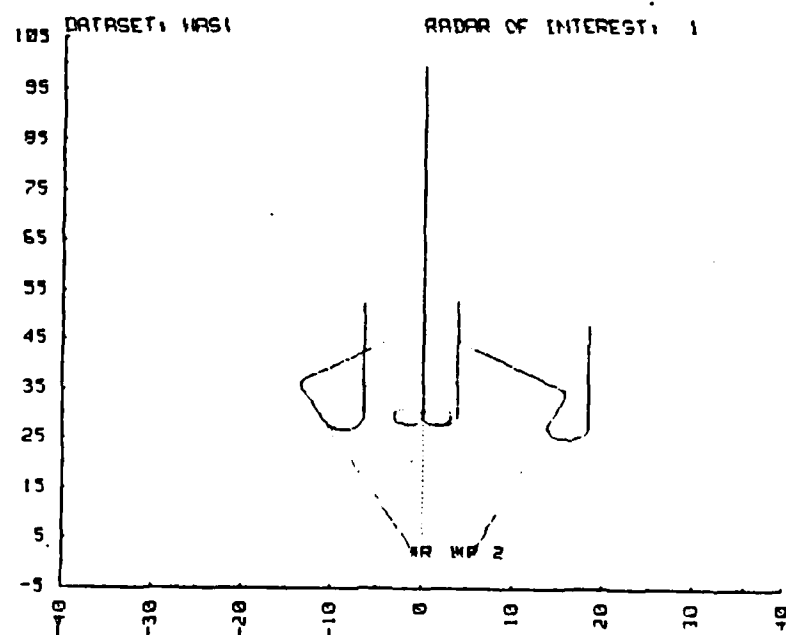


Figure 22. X-Y Plot for Radar 2; 105 nm Range

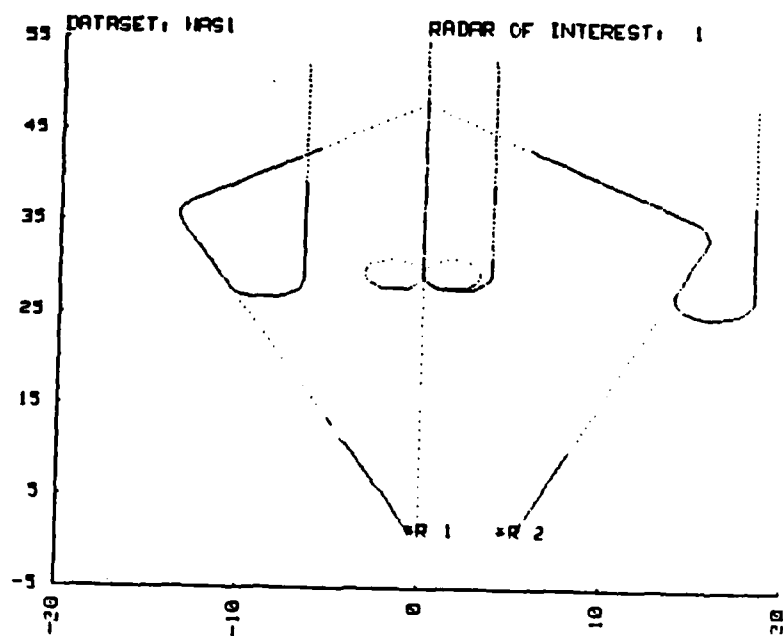


Figure 23. X-Y Plot for Radar 1; 55 nm Range

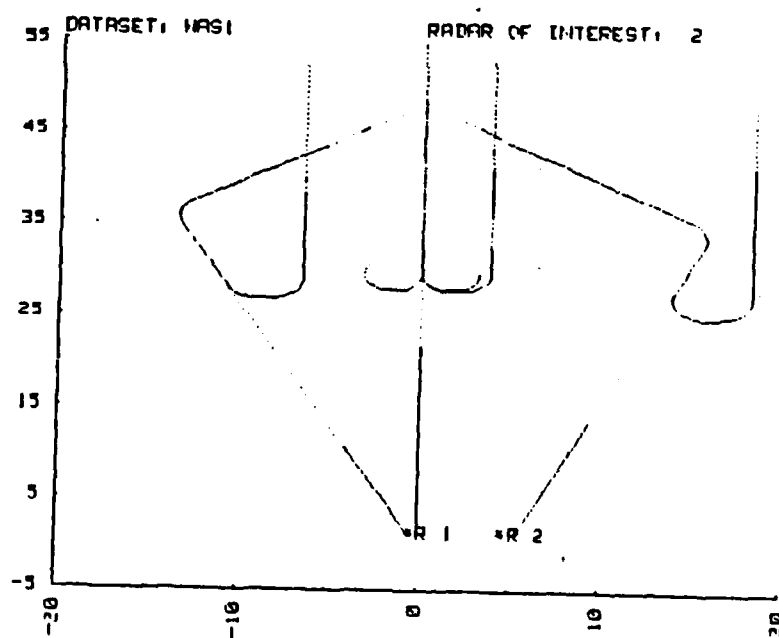


Figure 24. X-Y Plot for Radar 2; 55 nm Range

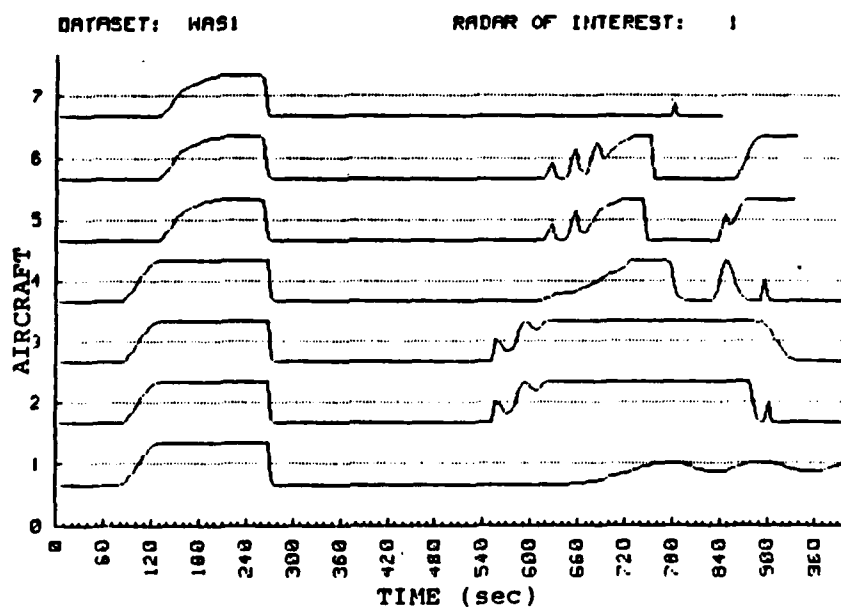


Figure 25. Probability of Detection per Scan Plot for Radar 1

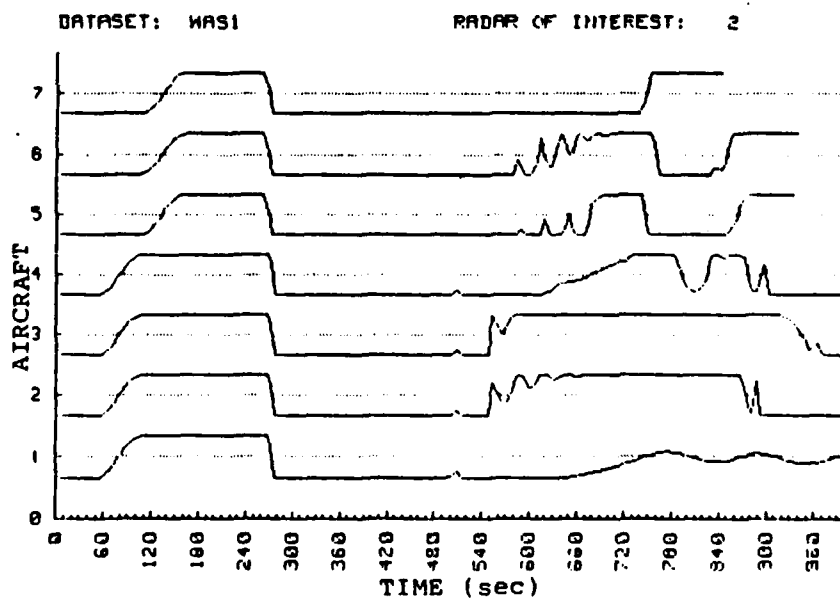


Figure 26. Probability of Detection per Scan Plot for Radar 2

FASTS STATISTICS OUTPUT DATASET: WAS1
 START TIME: 760

AIRCRAFT 5		DETECTION RANGE STATISTICS					
RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET	
1	11.762	1.674	10.907	11.670	13.198	1.000	
2	14.342	.749	13.900	14.260	14.622	1.000	

AIRCRAFT 6		DETECTION RANGE STATISTICS					
RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET	
1	11.605	.923	10.713	11.403	12.101	1.000	
2	14.399	.963	13.781	14.163	14.545	1.000	

AIRCRAFT 7		DETECTION RANGE STATISTICS					
RADAR	MEAN	STD DEV	.25 QNT	.50 QNT	.75 QNT	PCT DET	
1	NOT DET	NOT DET	NOT DET	NOT DET	NOT DET	0	
2	18.541	.323	18.260	18.762	18.762	1.000	

Figure 27. First Detection Statistics for Simulated Missiles

Due to his close alignment with the jamming axis, the ARM aircraft probably would not be detected by either ship's radar until just prior to launching his missile. Radar tracking would be solid through his outbound turn but would then degrade rapidly.

Both ASM's can be seen to be covered by jamming until well within their theoretical radar horizon of 19.7 miles. The statistical simulation predicts mean detection ranges for the ASM's of 11.8 and 11.6 miles by radar 1. Radar 2 ranges, 14.3 and 14.4 miles, were slightly higher due to the missiles' displacement from the jammer axis.

The ARM would not have been detected by radar 1; radar 2 may have detected the missile at as far as 18 nautical miles (from ship 2) when it would have been about 90 seconds from impact.

Missile coordination was satisfactory with ASM's impacting their targets with eight seconds separation following the arrival of the ARM by 1 minute and 32 seconds.

E. FOLLOW-ON SIMULATIONS

With the above results serving as a baseline, the scenario data file now can be modified to investigate and compare alternative plans or conditions. Such easily incorporated changes might include:

- Reduced altitudes for ASM launching aircraft
- Jammers accompanying ASM launching aircraft
- Different relative positionings of enemy ships
- Non-standard atmospheric conditions

VI. RESULTS AND CONCLUSIONS

The FASTS program developed in this thesis provides a consistent tool for use in the tactical planning process. It has demonstrated potential utility for: designing and simulating plans for coordinated tactical strikes; investigating radar visibility of aircraft under both standard and anomolous propagation conditions; and evaluating the effect of jamming on aircraft detection in a dynamic scenario.

Certain limitations exist in FASTS which must be recognized by a user in order to properly interpret the simulation results. Specifically, FASTS does not model:

1. Ship motion or the effect of wind which could easily alter the critical relative geometry of the simulation elements;
2. Radar transmission loss for targets above 10,000 feet altitude with verified accuracy;
3. Effects of jammer antenna blanking caused by maneuvering of the jammer aircraft;
4. Radar returns from sea clutter, an effect enhanced under ducting conditions, which may greatly reduce an operator's ability to discern an otherwise detectable target.

Areas for potential improvement to FASTS which could provide an increased simulation capability include incorporation of:

1. A standardized data base to include parameters for aircraft, radars, and jammers;
2. Missile profile routines to assess launch parameters and determine missile flight path vectors.

3. Transmission loss modeling for targets above 10,000 feet altitude;
4. Techniques for optimizing jammer placement as developed by T.W. White [Ref. 11] as a potential maneuvering control for jammer aircraft; and
5. Streamlined data and computation routines.

It is hoped that any future development effort for FASTS will not lose sight of its original objective--to provide a tactics testbed which can be used easily and interpreted by a fleet tactics planner. Evolution into a stockastic battle model would beget an increased level of complexity contrary to its intent.

APPENDIX A. FASTS PROGRAM SOURCE CODE

```

10  | ----- Fleet Anti-Ship Tactics Simulator -----
20  |
30  | FASTS supports the evaluation of a many-on-many scenario involving
40  | strike aircraft, support jammers, and air search radars. It is
50  | essentially a geometric model that computes the probability of
60  | a radar's detecting a target aircraft as a function of the S/J ratio
70  | observed at the radar receiver. The program draws directly from both
80  | the Modified Jamming Aircraft and Radar Simulation (JARSIM) Program/
90  | Johns-Hopkins Univ. APL and NOSC's IREPS radar loss model.
100 | .....
110 | .....
120 | BEGIN FASTS
130 | .....
140 | .....
150 | OPTION BASE 1
160 |
170 | INTEGER Nac,Njm,Nrd,Nsi,Nactyp,Ncp
180 | INTEGER Actype(15),Alpha(15,360),Ndeg(15),Change(15,15)
190 | INTEGER Cmm(15),Ac-(15,15),Acy(15,15),Dtype(15,2),Atsite(15)
200 | INTEGER Rdtyp(15),Nrdtyp,Output_choice,Rdr_choice,Rule,Hpolar(15,2)
210 | INTEGER Tc,Rdno
220 | INTEGER Inde-(15,360),Ndeg
230 | INTEGER A,I,J,K,M,Q,Ug,K,Tt
240 |
250 | INTEGER VARIABLES USED AS LOGICAL TYPES
260 | INTEGER Acc(15),Cmb(15),Turn(15),Hhom(15),Cscsq(15,2),Cross
270 | INTEGER Jmac(15,15),Nojam(15,15),Rdbtbt(15),Scanned(15,15)
280 | INTEGER Graphics_flag,Ship_flag(15),Follow(15),Stopnext(15)
290 |

```

```

300 REAL Aclat(15),Aclong(15),Aclat(15),Acvel(15),Achdg(15),Hdlat(15)
310 REAL Hdlong(15)
320 REAL Acaccl(15),Acclmb(15),Acturn(15),Tacc1(15),Tturn(15)
330 REAL Tc1mb(15),Acs(15,360),C1oc1(15,15)
340 REAL Jmbdw(15),Jmfrq(15),Jmerp(15),Jmpol(15),Jmeff(15,15)
350 REAL Rderptyp(15,2),Rdfrqtyp(15),Rdgantyp(15,2),Rdfntyp(15)
360 REAL Rdnbtwtyp(15),Loss(15),Rdscantyp(15),Rmaxtyp(15),Rvzerotyp(15)
370 REAL Rdalt(15),Rdant(15),Rdlat(15),Rdlong(15)
380 REAL Rdant(15,2),Rderp(15,2),Rdfrq(15),Rvzero(15)
390 REAL Rdgan(15,2),Rdgn(15),Rdmxt(15),Rdnbw(15),Rdscn(15)
400 REAL Rmax(15),Loss(15),Rdazbw(15,2),Rdazsl(15,2),Phi0(15,2)
410 REAL Rate(10),Deg_scanned(15),Exp2(15),Rdregn(15,2),Jampwr(15,2,15)
420 REAL R(15),Rn(15),H4(15),Phi(15),Theta(15)
430 REAL P1val(2),Fstlob(2),Seclob(2),Farlob(2),Xzero1(2),Xzero2(2)
440 REAL X3db(2),Coeff(2,3),X1(2),X2(2)
450 REAL Array(15,360),Irep_loss(15,2)
460 REAL Buffr(15,21),Old_buffr(15,21),Sim_rng(15,15,50)
470 I
480 ON ERROR GOTO Endit
490 GOTO Dsn I APPEND DATASET TO PROGRAM SOURCE CODE
500 I
510 Main I      ----- Main Program -----
520 I
530 GOSUE Init
540 GOSUE Setup
550 Stepclck 1sttut
560 IF I Tfin OF I 9999 THEN GOTO Exit
570 GOSUE Updac
580 GOSUE Updrd
590 GOSUE Outpt
600 GOTO Stepclck
610 I
620 I      ----- End Main Program -----

```

```

300 REAL Aclat(15),Aclong(15),Aclat(15),Acvel(15)
310 REAL Achdg(15),Hdlat(15),Hdlong(15)
320 REAL Acaccl(15),Acclmb(15),Acturn(15),Tacc1(15),Tturn(15)
330 REAL Tclmb(15),Rcs(15,360),Clccl(15,15)
340 REAL Jmbdw(15),Jmfrq(15),Jmerp(15),Jmpol(15),Jmeff(15,15)
350 REAL Rderptyp(15,2),Rdfrqtyp(15),Rdgantyp(15,2),Rdfntyp(15)
360 REAL Rdnbtwtyp(15),Losstyp(15),Rdscantyp(15),Rmaxtyp(15),Rvzerotyp(15)
370 REAL Rdalt(15),Rdart(15),Rdlat(15),Rdlong(15)
380 REAL Rdant(15,2),Rderp(15,2),Rdfrq(15),Rvzero(15)
390 REAL Rdgan(15,2),Rdfn(15),Rdmxt(15),Rdnbw(15),Rdscn(15)
400 REAL Rmax(15),Loss(15),Rdatbw(15,2),Rdazsl(15,2),Phi0(15,2)
410 REAL Rate(10),Deg_scanned(15),Exp2(15),Rdreqn(15,2),Jampwr(15,2,15)
420 REAL R(15),Rr(15),H4(15),Phi(15),Theta(15)
430 REAL Plval(2),Fstlob(2),Seclob(2),Farlob(2),Xzerol(2),Xzero2(2)
440 REAL X3db(2),Coeff(2,3),X1(2),X2(2),Sim_rng(15,15,50)
450 REAL Array(15,360),Irep_loss(15,2),Bufrc(15,21),Old_bufrc(15,21)
460 I
470 ON ERROR GOTO Endit
480 GOTO Dsn I APPEND DATASET TO PROGRAM SOURCE CODE
490 I
500 Main:I      -==== Main Program =====
510 I
520 GOSUB Init
530 GOSUB Setup
540 Stepclock  T=T+Dt
550 IF T Ifin OR T-9999 THEN GOTO Exit
560 GOSUB Updec
570 GOSUB Updrd
580 GOSUB Outpt
590 GOTO Stepclock
600 I
610 I      -==== End Main Program =====

```

```

620 I
630 Dsn I APPEND DATA SET
640 PRINTER IS CRT
650 PRINT PAGE
660 GINIT
670 GRAPHICS OFF
680 I APPEND DATA SET FILE TO PROGRAM SOURCE CODE.
690 DISP "ENTER DATASET FILE NAME: "
700 ENTER KBD:Ds_name$
710 PRINT TABXY(1,20):"LOADING DATASET FILE: ";Ds_name$;
720 DISP
730 GET Ds_name$,Dat
740 GOTO Main
750 I

```



```

760 Init 1 ==***INITIALIZE PROGRAM NON-ZERO VARIABLES***--
770 RANDOMIZE 92847
780 C=.1E1890 1 NM PER SEC / 1.0 E-6
790 Fd180=PI/180
800 D180pi=180./PI
810 Gfac=2/3
820 Graphics_flag=0
830 Zero=0
840 Rdr_choice=16
850 Ncp=15 1 MAX NUMBER OF FLIGHT COMMAND PROCEDURES FOR EACH AIRCRAFT
860 READ Pival(*) 1 ANTENNA HORIZ BEAM MODELING PARAMETERS
870 DATA 1.0,0.40526
880 READ Fst1ob(*)
890 DATA -13.27,-23.1
900 READ Sec1ob(*)
910 DATA -30,-30
920 READ Far1ob(*)
930 DATA -35,-35
940 READ Xzerol(*),Xzero2(*)
950 DATA 1,1.5,2,2.5
960 READ XGdb(*)
970 DATA 1.39156,1.8577
980 Coeff(1,1)=0.00348
990 Coeff(2,1)=0.0000754
1000 Coeff(1,2)=-0.047831
1010 Coeff(2,2)=-0.001292
1020 Coeff(1,3)=0.16522
1030 Coeff(2,3)=0.005657
1040 READ X1(*),X2(*)
1050 DATA 1.875,2.25, 2.25,2.75
1060 1

```

```

1070  DATA FOR FOLLOWING 'READ' STATEMENTS AT END OF PROGRAM (LABEL: DAT)
1080  READ Ds_names
1090  PRINT "DATASET " ; Ds_names
1100  WAIT 2
1110  READ Kfac, Ht_ductft, Wind
1120  READ Nac, Njm, Nrd, Nactyp, Nrdtyp, Dt, Tfin
1130  FOR R=1 TO Nrd  READ RADAR TYPE AND POSIT DATA
1140  READ Rdtyp(R), Rdlat(R), Rdlong(R), Rdalt(R)
1150  NEXT R
1160  !
1170  ! READ PARAMETERS FOR EACH RADAR TYPE
1180  FOR R=1 TO Nrdtyp
1190  READ Rdsentyp(R), Rdbbttyp(R), Rmaxtyp(R), Rvzerotyp(R)
1200  NEXT R
1210  FOR P=1 TO Nrdtyp
1220  READ Rderptyp(R,1), Rdrfrqtyp(R), Rdgantyp(R,1), Rdftyp(R), Kdnbttyp(R), Los
      styp(R)
1230  IF Rdbbttyp(R)=1 THEN READ Rderptyp(R,2), Rdgantyp(R,2)
1240  NEXT R
1250  Q=1
1260  FOR R=1 TO Nrdtyp
1270  READ Rdazbwttyp(R,Q), Pdazsltyp(R,Q), Rdelbwttyp(R,Q), Cscsqtyp(R,Q), Dtypety
      p(R,Q), Hpolar(R,Q)
1280  IF Q=1 AND Pdbbttyp(R)=1 THEN  ! IF PADAP HAS A BACK-TO-BACK ANTENNA.
1290  Q=2  ! NEXT DATA LINE CONTAINS 2ND ANTENNA
1300  GO TO 1270  ! PARAMETERS
1310  END IF
1320  Q=1
1330  NEXT R

```

```

1340 FOR I=1 TO Njm : READ JAMMER PARAMETERS
1350   READ Jmbdw(I),Jmfrq(I),Jmerp(I)
1360 NEXT I
1370 FOR I=1 TO Nactyp : READ RADAR CROSS SECTION DATA
1380   J=0
1390   Nextrcs:I
1400   J=J+1
1410   READ Alpha(I,J),Rcs(I,J)
1420   IF (Alpha(I,J)<>9999) THEN GOTO Nextrcs
1430   Ndeg(I)=J-1
1440 NEXT I
1450 I
1460 FOR A=1 TO Nac : READ ACFT TYPE AND INITIAL POSIT AND VELOCITY
1470   READ Actype(A),Aclat(A),Aclong(A),Achdg(A),Acvel(A)
1480 NEXT A
1490 FOR A=1 TO Nac : READ AIRCRAFT FLIGHT PROFILE DATA
1500   Skip_flag(A)=0
1510   Follow(A)=0
1520   Cmmnd(A)=1
1530   Tt=0
1540   Nexttime:I
1550   Tt=Tt+1
1560   READ Clock(A,Tt)
1570   IF Clock(A,Tt)<>9999 THEN
1580     READ Change(A,Tt),Ac<(A,Tt),Acy(A,Tt)
1590     GOTO Nexttime
1600   END IF
1610 NEXT A
1620 Minscan=100
1630 I

```

```

1640 1 MATCHES GENERAL TYPE PARAMETERS TO EACH RADAR
1650 1
1660 FOR P=1 TO Nrd 1 DETERMINES INITIAL ANTENNA POSIT
1670 Rdsen(R)=Rdsentyp(Rdtyp(R))
1680 Rdbtb(R)=Rdbtbtyp(Rdtyp(R))
1690 IF Rdbtb(R) THEN Rdant(R,2)=180
1700 Rma(R)=Rmaentyp(Rdtyp(R))
1710 Rdfrq(R)=Rdfrqtyp(Rdtyp(R))
1720 Rdfn(R)=Rdfntyp(Rdtyp(R))
1730 Rdnbw(R)=Rdnbwtyp(Rdtyp(R))
1740 Loss(R)=Lossyp(Rdtyp(R))
1750 Rvzero(R)=Rvzerotyp(Rdtyp(R))
1760 Q=1
1770 Rderp(R,Q)=Rderptyp(Rdtyp(R),Q)
1780 Ragan(R,Q)=Ragantyp(Rdtyp(R),Q)
1790 Rdaabw(R,Q)=Rdaabwtyp(Rdtyp(R),Q)
1800 Rdazsl(R,Q)=Rdazsltyp(Rdtyp(R),Q)
1810 Rdelbw(R,Q)=Rdelbwtyp(Rdtyp(R),Q)
1820 Cscsq(R,Q)=Cscsqtyp(Rdtyp(R),Q)
1830 Dtype(R,Q)=Dtypetyp(Rdtyp(R),Q)
1840 IF Q=1 AND Rdbtb(R)=1 THEN
1850 Q=2
1860 GO TO 1770
1870 END IF
1880 1

```

```

1880      '
1890      ' DETERMINE MIN ANTENNA SCANNING TIME OVER ALL RADARS
1900      IF Rdbtb(P)=1 THEN
1910          Temp1=Rdscn(R)*.5
1920      ELSE
1930          Temp1=Rdscn(R)
1940      END IF
1950      Minscan=MIN(Minscan,Temp1)
1960  NEXT R
1970  IF Dt Minscan THEN Dt=Minscan ' SET TIME INCREMENT TO MIN SCAN TIME
1980      ' IF LESS THAN INITIALLY DEFINED
1990      '

```

```

2000 I
2010 I INITIALIZE RADAR AND JAMMER PROGRAM CONSTANTS
2020 I
2030 FOR R=1 TO Nrd
2040 IF Rdbtb(R) THEN
2050 Q=2
2060 ELSE
2070 Q=1
2080 END IF
2090 FOR Qq=1 TO Q
2100 Rdat(R)=SQR(Pdalt(R))
2110 Deg_scanned(R)=360.*Dt/Rdson(P)
2120 Temp1=ABS(Rdgan(R,Qq))-ABS(Loss(R))
2130 Temp2=10.**(Temp1/10.)
2140 Temp3=(C/2)/(4*PI*Rdfrq(R)**2)
2150 Temp4=10.**(Rderp(R,Qq)/10)
2160 Rdreqn(R,Qq)=Temp2*Temp3*Temp4*2.9155E-7
2170 FOR J=1 TO Njm
2180 Jampwr(R,Qq,J)=(Jmerp(J)*Rdnbw(R)*Temp2*Temp3)/(Jmbdw(J)*2)
2190 Temp5=Jmbdw(J)*.5
2200 IF Qq=1 AND ABS(Rdfrq(R)-Jmfrq(J))>Temp5 THEN NoJam(R,J)=1
2210 NEXT J
2220 NEXT Qq
2230 NEXT R
2240 RETURN
2250 I
2260 I

```

```

2270 1  -----OUTPUT CHOICE AND SETUP ROUTINE-----
2280 Setup 1
2290     PRINTER IS CRT
2300     PRINT PAGE
2310     PRINT TABXY(5,5);Ds_names;" DATASET LOAD COMPLETE"
2320     PRINT TABXY(5,7);"SELECT OUTPUT MODE"
2330     PRINT TABXY(10,9);"[1] DATA"
2340     PRINT TABXY(10,10);"[2] X-Y PLOT"
2350     PRINT TABXY(10,11);"[3] PROB OF DETECTION PLOT"
2360     PRINT TABXY(10,12);"[4] FIRST-DETECTION STATS"
2370     PRINT TABXY(5,13);"USE RETURN KEY"
2380 Setup1 1
2390     ENTER KBD;Output_choice
2400     IF Output_choice=1 AND Output_choice=2 AND Output_choice=3 AND 0
      utput_choice=4 THEN
2410         BEEP
2420         DISP
2430         GOTO Setup1
2440     END IF
2450     IF Output_choice=2 OR Output_choice=3 THEN
2460         PRINT TABXY(5,15);"FOR GRAPHICS, ENTER RADAR OF INTEREST ";
2470 Setup2 1
2480     ENTER KBD;Rdr_choice
2490     IF Rdr_choice Nrd THEN
2500         BEEP
2510         DISP
2520         GOTO Setup2
2530     END IF
2540     PRINT Rdr_choice
2550     END IF

```

```

2560 PRINT TABXY(5,18);"ENTER OUTPUT START TIME: ";
2570 ENTER F80:Output_start
2580 PRINT Output_start
2590 WAIT 1.5
2600 PRINT PAGE
2610
2620
2630
2640
2650 IF Output_choice=1 OR Output_choice=4 THEN
2660 ON KEY 0 LABEL "0) PRINT" GOTO Printit
2670 ON KEY 7 LABEL "7) CRT" GOTO Crtit
2680 WAIT
2690 Printit:
2700 PRINTER IS 401
2710 Printno=401
2720 END IF
2730 Crtit:OFF KEY
2740 IF Output_choice=1 THEN
2750 PRINT "FAST5 DATA OUTPUT";SPA(10);"DATASET: ";Ds_names$
2760 OFF F80
2770 PRINT
2780 END IF
2790 IF Output_choice=4 THEN
2800 PRINT "FAST5 STATISTICS OUTPUT";TAB(39);"DATASET: ";Ds_names$
2810 PRINT "START TIME: ";Output_start
2820 GISE "WORKING"
2830 END IF
2840 RETURN

```



```

2950 1
2960 1 --***UPDATES AIRCRAFT POSITION, VELOCITY, AND JAMMER PARAMETERS***--
2970 Updac1:
2980 A=0
2990 Updac1:1 UPDATE ACFT POSITS AND PASS DATA TO BUFFER ARRAY
2990 A=A+1
2990 Buffr(A,1)=I
2990 IF Acvel(A)=0 THEN
2990 IF A=Nac THEN RETURN
2990 GO10 Updac1
2990 END IF
2990 Temp=D1*Acvel(A)/3600
2990 Temp1=Achdg(A)*Pid180
2990 Aclat(A)=Aclat(A)+Temp*COS(Temp1)
2990 Aclong(A)=Aclong(A)+Temp*SIN(Temp1)
2990 Buffr(A,2)=Aclat(A)
2990 Buffr(A,3)=Aclong(A)
2990 Buffr(A,4)=Aclat(A)
2990 Buffr(A,5)=Achdg(A)
2990 Buffr(A,6)=Acvel(A)
3000 Updac2:1 CHECK FLAG VARIABLES TO SEE IF ACFT IS IN A MANEUVER
3000 IF Accl(A) THEN GOSUB Accl1
3000 Buffr(A,6)=Acvel(A)
3000 IF Climb(A) THEN GOSUB Climb
3000 Buffr(A,4)=Acclat(A)
3000 IF Turn(A) THEN GOSUB Turn
3000 Buffr(A,5)=Achdg(A)
3000 IF Hnom(A) THEN GOSUB Home
3000 Tc=Cmmd(A)

```

```

3140 IF Clock(A,Tc) T THEN      TIME FOR NEXT MANEUVER?
3150   ON Change(A,Tc) GOSUB One,Two,Three,Four,Five,Six,Seven
3160   Cmd(A)=Cmd(A)+1 : UPDATE COMMAND LINE POINTER
3170   END IF
3180   IF A=Nac THEN GOTO Updaci
3190   FOR A=1 TO Nac
3200     IF Follow(A) THEN
3210       Aclat(A)=Aclat(Follow(A))
3220       Aclong(A)=Aclong(Follow(A))
3230       Acvel(A)=Acvel(Follow(A))
3240       Achdg(A)=Achdg(Follow(A))
3250       Acalt(A)=Acalt(Follow(A))
3260       Buffr(A,2)=Aclat(A)
3270       Buffr(A,3)=Aclong(A)
3280       Buffr(A,4)=Acalt(A)
3290       Buffr(A,5)=Achdg(A)
3300       Buffr(A,6)=Acvel(A)
3310     END IF
3320   NEXT A
3330   RETURN
3340

```

```

3350 One : TURN JAMMER ON
3360 Jamac(Acx(A,Tc),A)=1
3370 RETURN
3380 Two : TURN JAMMER OFF
3390 Jamac(Acx(A,Tc),A)=0
3400 RETURN
3410 Three : START ACCELERATION
3420 Acc1(A)=1 : FLAG ON
3430 Follow(A)=0
3440 Taccl(A)=ABS((Acy(A,Tc)-Acvel(A))/Acx(A,Tc)) : ACCEL TIME
3450 Acaaccl(A)=SGN(Acy(A,Tc)-Acvel(A))*ABS(Acx(A,Tc)) : ACCEL RATE
3460 RETURN
3470 Four : START CLIMB
3480 Clmb(A)=1 : FLAG ON
3490 Follow(A)=0
3500 Tc1mb(A)=ABS((Acy(A,Tc)-Acalt(A))/Acx(A,Tc)) : CLIMB TIME
3510 Acc1mb(A)=SGN(Acy(A,Tc)-Acalt(A))*ABS(Acx(A,Tc)) : CLIMB RATE
3520 RETURN
3530 Five : START TURN
3540 Turn(A)=1 : FLAG ON
3550 Hhom(A)=0 : TERMINATE ANY ACTIVE HOMING MANEUVER
3560 Follow(A)=0
3570 Temp=Acy(A,Tc)-Achdg(A) : DEGREES OF TURN
3580 Acturn(A)=Acx(A,Tc) : TURN RATE
3590 IF Temp 0 AND (Acturn(A) 0) THEN Temp=360-Temp
3600 IF Temp 0 AND (Acturn(A) 0) THEN Temp=360+Temp
3610 IF Temp 0 AND (Acturn(A) 0) THEN Temp=-Temp
3620 Tturn(A)=ABS(Temp/ncx(A,Tc)) : TIME FOR TURN
3630 RETURN

```

```

3540 31. 1 START HOMING
3650  Hhom(A)=1 1 FLAG ON
3660  Turn(A)=0 1 TERMINATE ANY ACTIVE TURN
3670  Follow(A)=0
3680  1 DEFINE HOMING TGT PARAMETERS
3690  Rano=Acy(A,Tc)
3700  Hdlat(A)=Rdlat(Rdno)
3710  Hdlong(A)=Rdlong(Rdno)
3720  1
3730  Acturn(A)=Acx(A,Tc) 1 TURN RATE
3740  RETURN
3750  Seven: 1
3760  Follow(A)=Acx(A,Tc)
3770  Acc1(A)=0
3780  Climb(A)=0
3790  Turn(A)=0
3800  Home(A)=0
3810  RETURN
3820  Accell: 1
3830  IF Tacc1(A)=D1 THEN
3840  Acvel(A)=Hcvel(A)+Acacc1(A)*D1 1 UPDATE SPEED
3850  Tacc1(A)=Tacc1(A)-D1 1 UPDATE ACCEL TIME REMAINING
3860  ELSE
3870  Acc1(A)=0 1 FLAG OFF
3880  Hcvel(A)=Hcvel(A)+Acacc1(A)*Tacc1(A) 1 UPDATE VELOCITY
3890  END IF
3900  IF Hcvel(A) 10 THEN Hcvel(A)=0 1 CLAMP SLOW MOVERS TO ZERO
3910  RETURN

```

```

3920 Climb :
3930 IF TcLmb(A):Dt THEN
3940   Acalt(A)=Acalt(A)+AccLmb(A)*Dt : UPDATE ALTITUDE
3950   TcLmb(A)=TcLmb(A)-Dt : CLIMB TIME REMAINING
3960 ELSE
3970   Clmb(A)=0 : FLAG OFF
3980   Acalt(A)=Acalt(A)+AccLmb(A)*TcLmb(A) : UPDATE ALTITUDE
3990 END IF
4000 RETURN
4010 Turn :
4020 IF Tturn(A):Dt THEN
4030   Achdg(A)=Achdg(A)+Acturn(A)*Dt : UPDATE HEADING
4040   Tturn(A)=Tturn(A)-Dt : TURN TIME REMAINING
4050 ELSE
4060   Turn(A)=0 : FLAG OFF
4070   Achdg(A)=Achdg(A)+Acturn(A)*Tturn(A) : UPDATE HEADING
4080 END IF
4090 IF Achdg(A):0 THEN Achdg(A)=Achdg(A)+360
4100 IF Achdg(A):=360 THEN Achdg(A)=Achdg(A)-360
4110 RETURN

```

```

4120 Home:
4130      I COMPUTE HEADING TO HOMING TGT
4140      Dlat=Hdlat(A)-AcLat(A)
4150      Dlong=Hdlong(A)-AcLong(A)
4160      IF SQR(Dlat^2+Dlong^2)<Acvel(A)*Dt/3600 THEN
4170          Acvel(A)=0
4180          RETURN
4190      END IF
4200      IF Dlat=0 AND Dlong>0 THEN Head=90
4210      IF Dlat=0 AND Dlong<0 THEN Head=270
4220      IF Dlat<0 THEN Head=ATN(ABS(Dlong/Dlat))*D180pi
4230      IF Dlat=0 AND Dlong=0 THEN Head=360-Head
4240      IF Dlat<0 AND Dlong<0 THEN Head=180+Head
4250      IF Dlat<0 AND Dlong>0 THEN Head=180-Head
4260      Temp=AcHdg(A)-Head
4270      I DEFINE TURN RATE I.E. DIRECTION OF TURN
4280      Acturn(A)=ABS(Acturn(A))
4290      IF Temp<0 AND Temp<180 THEN Acturn(A)=-Acturn(A)
4300      IF Temp<180 THEN Acturn(A)=-Acturn(A)
4310      IF Temp<180 THEN Temp=360-Temp
4320      IF Temp<180 THEN Temp=360+Temp
4330      Tturn(A)=ABS(Temp/Acturn(A)) I TIME FOR TURN
4340      GOSUB Turn
4350      RETURN
4360 I
4370 I

```

```

4380 I
4390 I  -....UPDATE PADAR ANTENNA POSITION, DETERMINE IF AIRCRAFT HAS.....
4400 I  -.... BEEN SCANNED, AND DETERMINE PROBABILITY OF DETECTION. ....
4410 Updrd I
4420 I=0
4430 Updrd1 I
4440 I=I+1
4450 IF I.Nrd OR I.Rdr_choice THEN RETURN
4460 IF Output_choice=2 OR Output_choice=3 THEN
4470 I=Rdr_choice
4480 Dt=Rdscn(I)
4490 IF Rdrhb(I) THEN Dt=Dt/2
4500 Deg_scanned(I)=360.*Dt/Rdscn(I)
4510 END IF
4520 h=0
4530 Updrd2 I
4540 I
4550 h=A+1
4560 IF A.Nac THEN GOTO Updrd3
4570 Scanned/h,I=0
4580 IF Acvel(h)=0 THEN GOTO Updrd2
4590 D.=Aclong(A)-Pdlong(I)
4600 IF D.=0 THEN D.=.0001
4610 D.=abs(D)-Pdlat(I)
4620 IF D.=0 THEN Dv=.0001
4630 Temp=Dv/Dt
4640 Dv=abs(Dv)-Pdalt(I)/6076.1
4650 IF Dv=0 THEN Dv=.001
4660 Temp1=Dv/Dt
4670 h=h+Temp+Temp1 / SLANT RANGE SQUARED
4680 Pr(A)=SQ(Pr(A)) / SLANT RANGE

```

```

4690 G-V=50P Temp1
4700 X=0.
4710 Y=0.
4720 GOSUB Aten2
4730 Phi(A)=Atng*D180pi
4740 IF Phi(A) < 0 THEN Phi(A)=Phi(A)+360
4750 Q=1
4760 GOSUB Irep : RETURNS Aloss
4770 Irep_loss(A,1)=Aloss : ONE WAY TRANSMISSION LOSS
4780 IF Rdbtb(1) THEN
4790 Q=2
4800 GOSUB Irep
4810 Iref_loss(A,2)=Aloss
4820 END IF
4830 Q=1
4840 GOTO Updrd2
4850 Updrd3 :
4860 Cross=0
4870 Pdant(1,Q)=Pdant(1,Q)+Deg_scanned(1) : NEW ANTENNA POSIT
4880 IF Pdant(1,Q) = 360 THEN Cross=1
4890 IF Pdant(1,Q) = 360 THEN Rdant(1,Q)=Rdant(1,Q)+360
4900 Temp2=Rdant(1,Q)+Deg_scanned(1) : OLD ANTENNA POSIT
4910

```



```

4920      I...CHECK TARGETS FOR POSSIBLE DETECTION...
4930      I
4940      A=0
4950      Updrd4:I
4960      A=A+1
4970      IF A=Nac THEN
4980          IF Rdbtb(I) AND Q=1 THEN
4990              Q=2
5000              GOTO Updrd3
5010          ELSE
5020              GOTO Updrd1
5030          END IF
5040      END IF
5050      IF Acvel(A)=0 OR R(A)=Rmax(I) THEN GOTO Updrd4
5060      IF Cross THEN I WAS THE AIRCRAFT SCANNED?
5070      IF Phi(A)=Rdant(I,Q) AND Phi(A)/Temp2+360 THEN Updrd4
5080      ELSE
5090      IF Phi(A)=Rdant(I,Q) OR Phi(A)/Temp2 THEN Updrd4
5100      END IF
5110      Scanned(A,I)=1
5120      I
5130      I...CALCULATE JAMMING POWER...
5140      I SUMS FWF INTO PADAR FROM ALL APPLICABLE JAMMERS
5150      Tot_noise=1.38E-23*290*10*(Rdfo(I)/10)*Rdnbw(I)*IE6
5160      J=0
5170      Updrd5:I
5180      J=J+1
5190      IF J=Jm THEN GOTO Updrd7
5200      IF NoJam(I,J) THEN GOTO Updrd5
5210      I=0

```

```

5220 Updrd6 1
5230 L=L+1
5240 IF L Nac THEN GOTO Updrd5
5250 IF Jmac(J,L)=0 OR Acvel(L)=0 THEN GOTO Updrd6
5260 Delphi=Phi(L)-Phi(A) 1 ANGLE BETWEEN JAMMER AND TGT ACFT
5270 IF Delphi =-180 THEN Delphi=Delphi+360
5280 IF Delphi 180 THEN Delphi=Delphi-360
5290 GOSUB Antpat 1 RETURNS SDL: SIDELOBE LOSS DUE TO DELPHI
5300 Temp=-ABS(Sdl)/-lrep_loss(L,Q)
5310 Temp1=10.^(Temp/10.)
5320 Tot_noise=Tot_noise+(Jampwr(1,Q,J)*Temp1) 1 SUMS FOR TOTAL JAMMING P
WR
5330 GOTO Updrd6
5340 1
5350 1***CALCULATE RADAR CROSS SECTION***
5360 1
5370 Updrd7 1
5380 M=Actype(A)
5390 Aspect=180+Phi(A)-Achdg(A)
5400 IF Aspect 360 THEN Aspect=Aspect-360
5410 IF Aspect 0 THEN Aspect=Aspect+360
5420 GOSUB Trcdlt
5430 Sigma=10.^(Sigdb/10)
5440 1

```

AD-A161 177

FASTS: A RADAR SIMULATION MODEL FOR THE DEVELOPMENT AND ANALYSIS OF AIRCRAFT ANTI-SHIP TACTICS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA F O BARRETT SEP 85

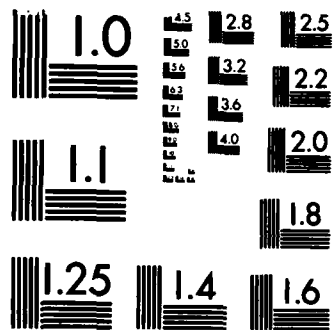
UNCLASSIFIED

F/G 17/9

NL

END

Q74C



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```

5450 *****CALCULATE PROBABILITY OF DETECTION*****
5460
5470 Signal=10*LGT(Rdreqn(I,Q)*Sigma)-2*Irep_loss(A,Q)
5480 Tot_noise=10*LGT(Tot_noise)
5490 Se=Signal-Tot_noise-Rvzero(I) ! SIGNAL EXCESS
5500 IF Se<-9 THEN Pd=0
5510 IF Se>9 THEN Pd=1
5520 IF Se>=-9 AND Se<=9 THEN Pd=(1+SIN(Se*PI/18))/2
5530 - Buffr(A,I+6)=Pd
5540 GO TO Updrd4
5550
5560 Output=I
5570 IF Output_start T THEN RETURN
5580 Nrdp5=Nrd+6
5590 SELECT Output_choice
5600
5610 CASE 1 ! DATA OUTPUT
5620 IF Nrd<4 THEN
5630 DISP "OUTPUT FORMAT CAN HANDLE ONLY 4 OR FEWER RADARS."
5640 WAIT 1.5
5650 GO TO Setup
5660
5670 ! HEADER AND FORMAT
5680 PRINT "ACFT TIME DX DY ALT HEADG SPEED "
5690 FOR P=1 TO Nrd
5700 PRINT "RADAR":R
5710 IF P=Nrd THEN PRINT
5720 NEXT P

```

```

5730 PRINT
5740 ' PRINTING ROUTINE
5750 FOR A=1 TO Nac
5760 IF Acvel(A) > 0 THEN
5770 PRINT USING "3D*":A
5780 FOR J=1 TO 6
5790 PRINT USING "5D.0*":Buffs(A,J)
5800 Old_buffr(A,J)=Buffs(A,J)
5810 NEXT J
5820 FOR J=1 TO Nrd
5830 IF NOT Scanned(A,J) THEN
5840 PRINT " *****"
5850 ELSE
5860 PRINT USING "3D.4D*":Buffs(A,J+6)
5870 END IF
5880 NEXT J
5890 PRINT
5900 END IF
5910 NEXT A
5920 PRINT
5930 '
5940 CASE 2 ' GRAPHICS OUTPUT
5950 IF Graphics_flag=1 THEN Picstart
5960 GOTO
5970 Picstart '
5980 Graphics_flag=1 ' FIRST TIME THRU ROUTINE
5990 PRINT PAGE
6000 PRINT TAB(1,5):"INPUT SCREEN BORDERS" ' USER FORMAT INPUT
6010 PRINT "LEFT "
6020 ENTER PIC.Left_edge
6030 DISP

```

```

6040 PRINT Left_edge
6050 PRINT "RIGHT: ";
6060 ENTER KBD:Right_edge
6070 DISP
6080 PRINT Right_edge
6090 IF Right_edge=Left_edge THEN
6100 DISP "RIGHT EDGE LESS THEN LEFT EDGE. TRY AGAIN."
6110 WAIT 2
6120 GOTO Rledges
6130 END IF
6140 Tbedges:
6150 PRINT TABXX(1,8):"BOTTOM: ";
6160 ENTER KBD:Bottom_edge
6170 DISP
6180 PRINT Bottom_edge
6190 PRINT "TOP: ";
6200 ENTER KBD:Top_edge
6210 DISP
6220 PRINT Top_edge
6230 IF Top_edge=Bottom_edge THEN
6240 DISP "TOP EDGE IS LESS THAN BOTTOM EDGE. TRY AGAIN"
6250 WAIT 2
6260 DISP
6270 PRINT TABYY(1,6):"
6280 PRINT "
6290 GOTO Tbedges
6300 END IF
6310 PRINT
6320 PRINT "DECLUTTER ? Y OR N "
6330 ENTER KBD:Tics$
6340 PRINT PAGE

```

```

6350 PEN 2 : RED
6360 Dw=Top_edge-Bottom_edge
6370 WINDOW 1.5*Left_edge,1.2*Right_edge,Bottom_edge-.1*Dw,Top_edge+.1*Dw
6380 CLIP Left_edge,Right_edge,Bottom_edge,Top_edge
6390 IF Title[1]="N" THEN
6400   LGRID 5,5
6410 ELSE
6420   LAXES 5,5,Left_edge,Bottom_edge,2,2,1
6430 END IF
6440 PEN 6 : BLUE
6450 FOR R=1 TO Nr-d : LABEL RADAR LOCATIONS
6460   PLOT Rdlong(R),Rdlat(R),-2
6470   LABEL CHR$(8):"@":
6480 NEXT R
6490 PEN 2 : RED
6500 PLOT Left_edge,Top_edge,-2 : LABEL PLOT
6510 LABEL "DATASET":":Ds_names
6520 PLOT (Left_edge+Right_edge)/2,Top_edge,-2
6530 LABEL "RADAR OF INTEREST":":Rdr_choice
6540 GRAPHICS ON

```



```

6550 Picstart '
6560   FOR A=1 TO Nac
6570     IF Acvel(A) < 0 THEN ' PLOT MOVING AIRCRAFT ONLY
6580     IF Slip_flag(A)=0 THEN Slip1
6590     IF Old_buffr(A,Rdr_choice+6)>=.5 THEN
6600       IF Buffr(A,Rdr_choice+6)>=.5 THEN
6610         LINE TYPE 1 ' SOLID LINE IF DET PROB > .5
6620         PEN 1 ' COLOR WHITE
6630       END IF
6640     ELSE
6650       LINE TYPE 2 ' DOTTED
6660       PEN 5 ' BLUE
6670     END IF
6680     Jam_flag=0
6690     FOR J=1 TO Njm
6700       IF Jamac(J,A) AND NOT Nojam(Pdr_choice,J) THEN Jam_flag=1
6710     NEXT J
6720     IF Jam_flag THEN
6730       PEN 4 ' GREEN FOR AIRCRAFT WITH ACTIVE JAMMERS
6740     END IF
6750     PLOT Old_buffr(A,3),Old_buffr(A,2),-2 ' MOVE PEN TO LAST POSIT
6760     PLOT Buffr(A,3),Buffr(A,2),-1 ' DRAW LINE TO NEW POSIT
6770     IF Abs(Old_buffr(A,3)-Buffr(A,3))>.5 THEN
6780       IF Buffr(A,3) MOD 60 < 0 THEN ' PLOT 1 MINUTE TICS
6790       IF Buffr(A,3) Left_edge AND Buffr(A,3) Right_edge THEN
6800         IF Buffr(A,2) Bottom_edge AND Buffr(A,2) Top_edge THEN
6810           PLOT Buffr(A,3),Buffr(A,2),-2
6820         LINE TYPE 1
6830         LABEL INT(Buffr(A,1)/60)
6840       END IF
6850     END IF
6860   END IF
6870 END IF

```

```

6990 Slip1=1
6990 Slip_flag(A)=1
6990 Old_buffr(A,2)=Buffr(A,2)
6990 Old_buffr(A,3)=Buffr(A,3)
6990 IF Buffr(A,Rdr_choice+6) > PI THEN
6990     Old_buffr(A,Rdr_choice+6)=Buffr(A,Rdr_choice+6)
6990 END IF
6990 END IF
6990 NEXT A
6990 FOR R=1 TO Nrd : RELABLES RADARS
6990     PEN 6 : BLUE
6990     PLOT Rdlong(R),Rdlat(R),-2
6990     LABEL CHR$(8):"Q"
6990 NEXT R
6990
7000
7010
7020
7030 CASE 3 : PROB DETECTION PLOT
7040 IF Graphics_flag THEN Plotstart
7050 GINIT
7060 Graphics_flag=1
7070 PEN 2
7080 WINDOW 1,1,Output_start-.1,Tfin,Tfin,-.25*Nac,Nac+2
7090 CLIP Output_start,Tfin,0,Nac+6fac
7100 LAYES 10,1,Output_start,0,5,1
7110 LINE TYPE 3
7120 FOR A=1 TO Nac
7130     PLOT Output_start,A,-2
7140     PLOT Tfin,A,-1
7150 NEXT A

```

```

7160 LINE TYPE 1 ' SOLID
7170 PLOT Output_start,Nact+1,-2
7180 LABEL "DATASET: ";Ds_names$
7190 PLOT (Output_start+Ifin)/2,Nact+1,-2
7200 LABEL "RADAR OF INTEREST: ";Rdr_choice
7210 GRAPHICS ON
7220 PEN 1
7230 Plotstart=1
7240 FOR A=1 TO Nac
7250 IF Acvel(A) = 0 THEN 'PLOT ONLY MOVING TGTS
7260 IF Ship_flag(A) THEN
7270 PLOT Tlast,Old_buffr(A,Rdr_choice+5)*Gfac+A-Gfac/2,-2
7280 PLOT T,Euffr(A,Rdr_choice+5)*Gfac+A-Gfac/2,-1
7290 END IF
7300 Ship_flag(A)=1
7310 Old_buffr(A,Rdr_choice+5)=Buffr(A,Rdr_choice+5)
7320 END IF
7330 NEXT A
7340 Tlast=T
7350

```

```

7360 CASE 4 1 STATISTICS ROUTINE
7370 Tsim=50 1 NUMBER OF SIMULATIONS
7380 Rule=2 1 OPERATOR FACTOR DETECTION FACTOR
7390 FOR A=1 TO Nac
7400   FOR R=1 TO Nrd
7410     Nrdp5=R+6
7420     IF Scanned(A,R) THEN
7430       FOR S=1 TO Tsim
7440         IF Sim_rng(A,R,S)=0 THEN 1 Sim_rng IS COUNTING RADAR HITS
7450         1 USE OPERATOR EFFICIENCY = .7*(Pd) FOR 1st HIT
7460         IF Sim_rng(A,R,S)=0 THEN
7470           Chance=0.7*Bufrr(A,Nrdp5)
7480         ELSE
7490           Chance=Bufrr(A,Nrdp5)
7500         END IF
7510         IF Chance=RND THEN 1 CONSECUTIVE RADAR HIT?
7520         Sim_rng(A,R,S)=Sim_rng(A,R,S)+1 1 INCREMENT COUNTER
7530       ELSE
7540         Sim_rng(A,R,S)=0 1 RE-INITs CONSECUTIVE HIT COUNTER
7550       END IF
7560       IF Sim_rng(A,R,S)=-Rule THEN 1 DETECTION RULE MET?
7570       Temp=(Bufrr(A,2)-Rdlat(R))2+ (Bufrr(A,3)-Rdlong(R))2
7580       Sim_rng(A,R,S)=SQRT(Temp) 1 STORES DETECTION RANGE
7590     END IF
7600   END IF
7610   NEXT S
7620   END IF
7630   NEXT R
7640   NEXT A
7650   END SELECT
7660 RETURN
7670 1

```

```

7580 I
7590 Output_stats I
7700 FOR A=1 TO Nac
7710 DISP "SORTING"
7720 FOR R=1 TO Nrd I BUBBLE SORT OF SIMULATION DETECTION RANGES
7730 REPEAT
7740 Sorted=1
7750 FOR S=1 TO Tsim-1
7760 IF Sim_rng(A,R,S)>Sim_rng(A,R,S+1) THEN
7770 Sorted=0
7780 Dummy=Sim_rng(A,R,S)
7790 Sim_rng(A,R,S)=Sim_rng(A,R,S+1)
7800 Sim_rng(A,R,S+1)=Dummy
7810 END IF
7820 NEXT S
7830 UNTIL Sorted
7840 NEXT R
7850 I COMPUTE STATISTICS
7860 PRINT
7870 PRINT
7880 PRINT "AIRCRAFT " A, "DETECTION RANGE STATISTICS"
7890 PRINT "RADAR MEAN STD DEV .25 QNT .50 QNT .75 QNT
PC1 DET"
7900 FOR R=1 TO Nrd
7910 PRINT R:
7920 Start=1

```

```

7930 Stat1=1
7940 DETERMINE INDEX FOR FIRST NON-ZERO DETECTION RANGE
7950 IF Stat1=1 THEN
7960   IF Sim_rng(A,R,Stat1)=0 THEN
7970     Stat1=Stat1+1
7980     GOTO Stat1
7990   END IF
8000 END IF
8010 ,
8020 IF Stat1=1 THEN , TARGET NOT DETECTED IN ANY OF SIMULATIONS
8030 PRINT "      NOT DET      NOT DET      NOT DET      NOT DET
0"

8040 ELSE , TARGET DETECTED AT LEAST ONE TIME
8050   Mean=Stdev=0
8060   ,
8070   FOR S=Stat1 TO 1sim
8080     Mean=Mean+Sim_rng(A,R,S)
8090   NEXT S
8100   Mean=Mean/(1sim-Stat1+1)
8110   ,
8120   FOR S=Stat1 TO 1sim
8130     Stdev=Stdev+(Sim_rng(A,R,S)-Mean)^2
8140   NEXT S
8150   IF 1sim=Stat1 THEN
8160     Stdev=SQRT(Stdev/(1sim-Stat1))
8170   ELSE
8180     Stdev=0
8190   END IF
8200   ,

```

```

8210      * DETERMINE QUANTILES
8220      Dummy=(Tsim-Start+1)/4
8230      IF Dummy MOD 1=0 THEN
8240          Qt25=(Sim_rng(A,R,Start+Dummy-1)+Sim_rng(A,R,Start+Dummy))/2
8250      ELSE
8260          Qt25=Sim_rng(A,R,Start+INT(Dummy))
8270      END IF
8280      Dummy=Dummy+Dummy
8290      IF Dummy MOD 1=0 THEN
8300          Qt50=(Sim_rng(A,R,Start+Dummy-1)+Sim_rng(A,R,Start+Dummy))/2
8310      ELSE
8320          Qt50=Sim_rng(A,R,Start+INT(Dummy))
8330      END IF
8340      Dummy=Dummy*3/2
8350      IF Dummy MOD 1=0 THEN
8360          Qt75=(Sim_rng(A,R,Start+Dummy-1)+Sim_rng(A,R,Start+Dummy))/2
8370      ELSE
8380          Qt75=Sim_rng(A,R,Start+INT(Dummy))
8390      END IF
8400      *
8410      Fctdet=(Tsim-Start+1)/Tsim
8420      *
8430      PRINT "Q25:",Qt25
8440      PRINT "Q50:",Qt50
8450      PRINT "Q75:",Qt75
8460      PRINT "Fctdet:",Fctdet
8470      *

```

```

8480 IF R=NAC THEN FLIP
8490 IF PRINTNO > 401 THEN
8500 DISP "DEPRESS CONT"
8510 PAUSE
8520 DISP
8530 END IF
8540 FLIP NEXT A
8550 RETURN
8560 I
8570 Trpolt1 USES ASPECT TO SOLVE RADAR X-SECTION BY INTERPOLATION
8580 I OUTPUT Sigdb
8590 IF Value Index(M,I) THEN GOTO Trpolt2
8600 Ii=I
8610 E1=Index(M,I)
8620 E2=0
8630 Trpolt1 I
8640 Ii=Ii+1
8650 IF Ii Ndeg(M) THEN GOTO Trpolt3
8660 E2=Alpha(M,Ii)
8670 IF Aspect=E2 THEN E1=E2
8680 IF Aspect=E2 THEN GOTO Trpolt1
8690 Diff=Aspect-E1
8700 Sigdb=Pos(M,Ii-1)+Diff*(Pos(M,Ii)-Pos(M,Ii-1))/(E2-E1)
8710 RETURN
8720 Trpolt1 I
8730 Repeat=Aspect+350
8740 Trpolt2 I
8750 Diff=Aspect-Alpha(M,Index(M)
8760 Sigdb=Pos(M,Ndeg(M))+Diff*(Pos(M,I)-Pos(M,Ndeg(M)))/(Alpha(M,I)-Alpha(M,Ndeg(M)))
8770 RETURN

```



```

8780 1
8790 Antpat=1 RETURNS JAMMING ATTENUATION DUE TO AZIMUTH SEPARATION
8800 Limit=-40
8810 Zero=0.
8820 Xlob8=8.5
8830 Sd1=Pid2=PI/2.
8840 Jj=Dtype(1,0)
8850 Conv=x3db(Jj)/(Rda=bw(1,0)*0.5)
8860 Adel=ABS(Delphi*Conv)
8870 IF Adel=Zero THEN
8880     Sd1=Zero
8890     RETURN
8900 END IF
8910 IF Adel<30*Conv THEN
8920     Sd1=Farlob(Jj)
8930     RETURN
8940 END IF
8950 IF Jj=1 THEN
8960     IF Rda=bw(1,0)*2 AND Adel<Xlob8*PI THEN
8970         Sd1=Farlob(Jj)
8980         RETURN
8990     END IF
9000     Temp=(SIN(Adel)/Adel)**2
9010     IF Temp<1E-4 THEN
9020         Sd1=Limit
9030         RETURN
9040     END IF
9050     Temp1=-10.*LG((PI*val(Jj))/Temp)
9060     IF Adel<Xzerol(Jj)*PI THEN
9070         Sd1=Temp1
9080         RETURN

```

```

9090 END IF
9100 IF Adel > zero2(Jj)*PI THEN Temp1=Temp1-(Fstlob(Jj)-Rdazsl(I,Q))
9110 IF Adel < zero2(Jj)*PI THEN Temp1=Temp1-6
9120 IF Temp1 < Limit THEN Temp1=Limit
9130 END IF
9140 IF Jj=2 THEN
9150 IF Adel < X2(Jj)*PI THEN
9160 Sdl=Seclob(Jj)
9170 RETURN
9180 END IF
9190 IF Adel = X1(Jj)*PI THEN
9200 Temp=Coeff(Jj,1)*Adel^2+Coeff(Jj,2)*Adel+Coeff(Jj,3)
9210 ELSE
9220 IF ABS(Adel-Pid2) = 1E-5 THEN
9230 Temp=0.25
9240 ELSE
9250 Temp=(Pid2-COS(Adel))/(Pid2^2-Adel^2)^2
9260 END IF
9270 END IF
9280 IF Temp > 4.053E-4 THEN
9290 Sdl=Seclob(Jj)
9300 RETURN
9310 END IF
9320 Temp1=-10*LGT(PI*val(Jj)/Temp)
9330 END IF
9340 Sdl=Temp1
9350 RETURN
9360
9370

```

```

9390 Atang = RETURNS ARC(RADIANS) OF ANGLE SUBTENDED BY Xx AT Yy
9390 IF Xx=0 AND Yy=0 THEN Atng=ATN(Xx/Yy)
9400 IF Xx=0 AND Yy=0 THEN Atng=PI+ATN(Xx/Yy)
9410 IF Xx=0 AND Yy=0 THEN Atng=2*PI+ATN(Xx/Yy)
9420 IF Xx=0 AND Yy=0 THEN Atng=PI+ATN(Xx/Yy)
9430 RETURN
9440
9450
9460 Irep = RETURNS 1-WAY SIGNAL LOSS BETWEEN RADAR AND TARGET ACFT.
9470 ALGORITHMS AND SOURCE CODE DERIVED FROM IREPS REV 2.2,
9480 LOSS SUBROUTINE (NOSC, SAN DIEGO, CA.)
9490 Antbwr=1.745E-2*Rdelbw(I,Q)
9500 Antelr=.01745
9510 Elma.r=1.047
9520 IF NOT (scsq(I,0) THEN
9530 Antfac=1.39157/SIN(Antbwr/2)
9540 Patrfac=-(Elma.r-Antelr)
9550 ELSE
9560 Elma.r=Antelr+.78525
9570 END IF
9580 60306 Surface_unit
9590 60506 Diffract_const

```

```

9600 IF Rm =Dmin THEN
9610   RANGE IS LESS THAN MINIMUM DIFFRACTION FIELD RANGE
9620   GOSUB Optical_limit
9630   IF Rm >Opmax THEN
9640     Rng=Dmin
9650     GOSUB Diffraction
9660     INTERPOLATE BTWN OPMAX AND DMIN TO OBTAIN ALOSS
9670     Aloss=Oploss+(Oploss-Diff)*(Rm-Opmax)/(Opmax-Dmin)
9680   ELSE
9690     IF Atheta <2*PI THEN
9700       RANGE IS LESS THAN OPMAX AND GREATER THAN OPEAK
9710       Thnext=2*PI
9720       GOSUB Plmda
9730       Opeal=Rnext
9740       Rng=Opeal
9750       IF Rm >Opeal THEN
9760         GOSUB Oploss
9770         Plloss=Aloss
9780         INTERPOLATE TO OBTAIN LOSS BTWN OPMAX AND 1ST OPTICAL PEAK
9790         Aloss=Plloss-(Oploss-Plloss)*(Rm-Opeal)/(Opeal-Opmax)
9800       ELSE
9810         LOSS IS IN THE ENVELOPE REGION (Rm > OPEAK)
9820         R=Rm
9830         GOSUB Theta
9840         Rng=Rm
9850         Atheta=TwoPI
9860         GOSUB Oploss
9870       END IF

```



```

10180 Twopi=2*PI
10190 Halfpi=PI/2
10200 F14cw1=.04198*Rdfrq(I) + 4*PI OVER WAVELENGTH
10210 Horizn=3.572*(SOR(Kfac*Ht)+SOR(Kfac*Hr))
10220 Dmin=Horizn+230.2*(Kfac*Kfac/Rdfrq(I))^(1/3)
10230 Hbfreq=.02094*Rdfrq(I)+5.1E-3*Wind*Wind
10240 Hfol=Hbfreq*.159155
10250 IF Rdfrq(I) 1500 THEN 10290
10260 Epslon=90
10270 Sigma=4.3
10280 GO TO 10350
10290 IF Rdfrq(I) 3000 THEN 10330
10300 Epslon=80-.00733*(Rdfrq(I)-1500)
10310 Sigma=4.3+.00148*(Rdfrq(I)-1500)
10320 GO TO 10350
10330 Epslon=69-.00243*(Rdfrq(I)-3000)
10340 Sigma=6.52+.001314*(Rdfrq(I)-3000)
10350 Sigom=-Sigma*18000/Rdfrq(I)
10360 Delx=Arma./50
10370 Delx2=Delx/2

```

```

10390 Kmag=1
10390 Phi=PI
10400 Ref_flag=0
10410 RETURN
10420 I
10430 I
10440 Optical_limit=1 GEOMETRIC MODEL FOR HR 10K FT
10450 Altrap=0 I DUCTING NOT USED IN OPTICAL REGION
10460 Dh=(Hr-Ht)*1E-3
10470 Ae2=Ae*2E-3
10480 Twoae=2*Ae
10490 Thefac=4.193E-5*Rdfrq(I)
10500 Vfac=(Ht+Hr)*Ae*1E-3
10510 Aetht=Ae*Ht*1E-3
10520 A1=SQR(Psi)**2+2E-3*Ht/Ae
10530 D1=D2=(A1-Psi)*Ae
10540 IF Hr Ht THEN D2=D2+(SQR(A1**2+2*Dh/Ae)-A1)*Ae
10550 D=D1+D2
10560 Htp=Ht-D1**2/Ae2
10570 Hrp=Hr-D2**2/Ae2
10580 Apd=Thefac*Htp*Hrp/D
10590 IF Hpolat(1,0)=0 THEN
10600 Sinpsi=SIN(Psi)
10610 COSUB Ref
10620 ENG IF
10630 Atheta=Apd+Phi
10640 Aelipna=Dh/D-D Twoae
10650 Krow=0
10660 IF (Apd Halfpi) OR (Psi Psilim) THEN C2
10670 C1 I GRAZING ANGLE LIMIT

```

```

10680 Innext=PI
10690 GOTO 10830
10700 C2 = QUARTER WAVELENGTH LIMIT
10710 Innext=3*Halfpi
10720 Know=.95*Horizn
10730 GOSUB Rlmda
10740 Know=Knext
10750 IF Hpolat(1,0)=0 THEN
10760 Psi=Htp*IE-3/01
10770 Sinpsi=SIN(Psi)
10780 GOSUB Ref
10790 Ref_flag=1
10800 Theta=4pd+Phi
10810 END IF
10820 GOTO C1
10830 Rng=Rsave=Pnow
10840 Opma=Rng
10850 GOSUB Optoss
10860 Optoss=Aloss
10870 RETURN
10880 I
10890 I
10900 Optoss = OPTICAL REGION LOSS
10910 R=Rng
10920 IF Ref_flag THEN 10950
10930 Psi=Htp*IE-3/01
10940 Sinpsi=SIN(Psi)
10950 Halpna=Phi/D-0.1ucos
10960 IF Halpna Elma.r THEN RETURN
10970 Gamma=D1-Ae

```



```

10980 Beta=-(Gamma+Psi)
10990 GO SUB F_factor
11000 Losfac=Fsterm+8.686*LOG(Rng)
11010 IF Ffac=1E-7 THEN Aloss=Losfac+70
11020 IF Ffac=1E-7 THEN Aloss=Losfac-4.343*LOG(Ffac)
11030 E_loss=-8.686*LOG(Patd)
11040 RETURN
11050 I
11060 I
11070 Rlmda: SUBROUTINE TO FIND RANGE WHERE A SPECIFIED VALUE OF THETA OCCURS
11080 I RLMda USES A FINITE DERIVATIVE IN A NEWTON ITERATION FOR THETA
11090 I INPUTS: RNOW; OI: THNEXT; HTP; ATHETA
11100 I OUTPUTS: RNEXT
11110 I SUBROUTINES USED: THETA
11120 I CONSTANTS: HORIZN
11130 Psave=OI
11140 O=Rnow
11150 Dinc=MIN(.1,D*.01)
11160 FOR Icount=1 TO 10
11170 GO SUB Theta
11180 F=ATHeta
11190 O=O+Dinc
11200 GO SUB Theta
11210 F1=ATHeta
11220 Fp=(F1-F)/Dinc
11230 Od=-(F-Thnext)/Fp
11240 IF O3=O THEN 11270
11250 O=O2
11260 GO TO 11220

```

```

11270 IF Horizon D+Dd THEN 11300
11280 D=(Horizon+D)/2
11290 GOTO 11320
11300 D=D+Dd
11310 IF (ABS(Dd) Dinc) AND (D Rnow) THEN 11330
11320 NEXT Icount
11330 Rnext=D
11340 RETURN
11350
11360
11370 Theta : SUBROUTINE FOR TOTAL PHASE DIFF, THETA, BTWN DIR AND REFL RAYS
11380 : SOLVES A CUBIC EQN TO FIND REFLECTION POINT RANGE DI
11390 : INPUTS D
11400 : OUTPUTS ATHETA, DI: APO: HTP: PSI: SINPSI
11410 : CONSTANTS UFAC: AETHT: PHI: AEC: THEFAC
11420 : SUBROUTINES USED: REF
11430 At=-1.5*D
11440 U=.5*D/2-UFAC
11450 W=Aetht*D
11460 FOR Inde=1 TO 10
11470 Disq=D/2
11480 Fd1=D1+Disq+At+Disq+U+D1+W
11490 Fpd1=2*Disq+2*(U+At+U
11500 Dela=Fd1-Fpd1
11510 D1=D1-Dela
11520 IF (D1 D) AND (D1 0) THEN 11550
11530 D1=D/2
11540 GOTO 11560
11550 IF ABS(Dela) .100 THEN 11570
11560 NEXT Inde

```

```

11570 D2=D-D1
11580 Htp=Ht-B1*D1/Ae2
11590 Hrp=Hr-D2*D2/Ae2
11600 IF NOT Ref_flag THEN 11640
11610 Psi=Htp*IE-3/D1
11620 Sinpsi=SIN(Psi)
11630 GOSUB Ref
11640 hpd=Hr*fac*Htp*Hrp/D
11650 Atheta=Apd+Phi
11660 RETURN
11670 I
11680 I
11690 Diffract_const=1 DIFFRACTION/TROPOSCATTER REGION CONSTRAINTS
11700 Freq=Rdfrq/I
11710 IF Ht_duct=0 THEN Evap_duct
11720 I CONSTANTS FOR GROUND-BASED DUCT
11730 Atten=0
11740 Tlrfac=2
11750 Tl=Hr/Ht_duct
11760 IF (Freq=150) AND (Tl<.8) THEN F2=-60*(Tl+.5)^2
11770 IF (Freq=150) AND (Tl>=.8) THEN F2=1.14*Tl*(-6.26)-10
11780 IF (Freq=150) AND (Tl=1) THEN F2=10-200*(Tl-.5)^4
11790 IF (Freq=150) AND (Freq=350) AND (Tl=1) THEN F2=7.5*Tl*(-13.3)-10
11800 IF (Freq=350) AND (Tl=1) THEN F2=12.5*Tl*(-8)-15
11810 Gifac=Fsterm-F2+E_loss
11820 GOF=Incpo

```

```

11230 Evap_duct=1  STANDARD DIFF. CONETANTS
11840 Tlrfac=1
11250 Rfac=4.705E-2*Freq**(1/3)
11860 Zfac=2.214E-3*Freq**(2/3)
11870 Hmin=1/Zfac
11880 Zt=MAX(Hmin,Ht*Zfac)
11890 Zr=MAX(Hmin,Hr*Zfac)
11900 C1=-14.8
11910 C2=.49
11920 C3=-36.9
11930 C4=-.1
11940 C5=102
11950 Fzt=C1*(Zt/4.72)**C2+C3*(Zt/4.72)**C4+C5
11960 Fzr=C1*(Zr/4.72)**C2+C3*(Zr/4.72)**C4+C5
11970 Atten=1.973*Rfac
11980 Tlm=216.7
11990 Difac=51.1+Tlm-Fzt-Fzr+4.343*LOG(Rfac)
12000 Tropo=1
12010 Tfac=.08994/Kfac
12020 Trofac=13.029*LOG(Freq)+49.9-Tfac*HorizntE_loss
12030 RETURN
12040=1
12050=1
12060 Diffraction=1  RETURNS LOSS IN DIFFRACTION/TROPOSCATTER REGION @ RNG
12070=1  INPUTS  RNG
12080=1  OUTPUTS  DIFF
12090=1  CONSTANTS  Tfac, Trofac, Difac, Atten, Tlrfac
12100 Tlr=4.343*LOG(Rng)
12110 Tloss=Tfac*Rng+2*Tlr+Trofac
12120 Dlf=Difac+Tlr*Tlrfac+Atten*Rng
12130 Dlf=Dlf-Tloss

```

```

12140 IF Dif = 19 THEN RETURN
12150 IF Dif = 18 THEN
12160   Diff=Diff-4.343*LOG(1+EXP(Dif/4.343))
12170 ELSE
12180   Diff=Tloss
12190 END IF
12200 RETURN
12210 RETURN
12220 I
12230 I
12240 Antpat=1 *** ANTENNA PATTERN FUNCTION SUBROUTINE ***
12250 I INPUTS: ELEVATION ANGLE FOR WHICH ANTENNA PATTERN DESIRED: ANGLE
12260 I OUTPUTS: NORMALIZED ANTENNA PATTERN FACTOR: PATFAC
12270 I CONSTANTS: ANTEL: ANTFAC; ANTBWR: PATRFAC;
12280 Patfac=1
12290 Apat=Angle-Antelr
12300 IF Cosq(1,0) THEN 12380
12310 IF ABS(Apat).1E-6 THEN RETURN
12320 IF Angle-Antelr+Patrfac THEN 12350
12330 Patfac=0.03
12340 RETURN
12350 Ufac=Antfac*SIN(Apat)
12360 Patfac=ABS(SIN(Ufac))/Ufac)
12370 RETURN
12380 Patfac=MIN(1,MAX(.03,1+Apat/Antbwr))
12390 IF Apat-Antbwr THEN Patfac=Antbwr/SIN(ABS(Apat))
12400 RETURN
12410 I

```

```

12420 I
12430 Ruf=1 RETURN SURFACE ROUGHNESS COEFFICIENT FOR SPECIFIED GRAZING ANGLE
12440 I INPUT SURFACE ROUGHNESS IS FUNCTION OF WIND SPEED.
12450 I INPUTS GRAZING ANGLE: PSI: SIN(PSI)
12460 I OUTPUTS NORMALIZED MAGNITUDE OF REFLECTED SIGNAL: RUF
12470 I CONSTANTS: HBFREQ: HFOL
12480 Eterm=-2*(Hbfreq*Sinpsi)^2
12490 IF Eterm<-.95555 THEN 12520
12500 RUF=EXP(Eterm)
12510 RETURN
12520 Hfpsi=Hfol*Psi
12530 IF Hfpsi<.26 THEN RUF=.15
12540 IF Hfpsi>=.15 THEN RUF=.5018913-SQR(.2090248-(Hfpsi-.55189)^2)
12550 RETURN
12560 I
12570 I
12580 Ref=1 REFLECTION COEFFICIENT
12590 Rr=Epsilon-COS(Psi)^2
12600 Ar=(Rr*Pr+Sigom*Sigom)^.25
12610 Th=ATAN(Sigom*Pr)/2
12620 Rr=Rr+COS(Th)
12630 Ry=Rr*SIN(Th)
12640 Aa=Epsilon*Sinpsi-Rr
12650 Ab=Sigom*Sinpsi-Ry
12660 Ac=Epsilon*Sinpsi+Rr
12670 Adx=Sigom*Sinpsi+Ry
12680 Rr=(Ar*Ar+Ab*Ab+.77*Ac*Ac+Ad*Ad)
12690 Ry=(Ar*Ar+Ab*Ab+.77*Ac*Ac+Ad*Ad)
12700 Rmag=SQR(Rr+Ry)

```

```

12710 IF R=0 THEN
12720   PHI=ATN(P./R.)
12730   IF R=0 THEN PHI=PHI+PI
12740 ELSE
12750   IF RY=0 THEN PHI=-Halfpi
12760   IF RY>0 THEN PHI=Halfpi
12770   IF RY<0 THEN PHI=0
12780 END IF
12790 PHI=-PHI
12800 IF PHI=0 THEN PHI=PHI+Twopi
12810 IF NOT HPolar(I,Q) THEN RETURN
12820 R.=SQRT(1+Rmag*Rmag+2*Rmag*COS(PI-PHI))
12830 Aa=ASN(Rmag*SIN(PHI+PI)/R.)
12840 PHI=PI-Aa
12850 Rmag=R./2
12860 PHI=-PHI
12870 IF PHI=0 THEN PHI=PHI+Twopi
12880 RETURN
12890 I
12900 I
12910 F_factor I RETURN VALUE OF PATTERN PROPAGATION FACTOR: F
12920 I INPUTS ANGLES PSI: AALPHA: BETA: GAMMA: HR: RMAG:
12930 I ATHETA: PATFAC
12940 I OUTPUTS: FFAC
12950 I SUBROUTINES CALLED: AANTPAT, RUF
12960 Angle=alpha
12970 GOSUB Aantpat
12980 Patd=ffac
12990 Angle=beta
13000 GOSUB Aantpat
13010 GOSUB RUF

```

```

13020 Divfac=1/SQR(1+2*gamma/Sinpsi)
13030 Dr=Divfac*Patfac*kmag*Ruf
13040 Ffac=Patd**2+Dr**2+Dr*Patd*COS(Atheta)
13050 RETURN
13060 I
13070 Exit:
13080 SELECT Output_choice
13090 CASE 1: DATA
13100 CASE 2: X-Y PLOT
13110 ON KEY 0 LABEL "0" DUMP " GOTO Dumpit
13120 CASE 3: PD PLOT
13130 ON KEY 0 LABEL "0" DUMP " GOTO Dumpit
13140 CASE 4: STATS
13150 GOSUE Output_stats
13160 END SELECT
13170 ON KEY 7 LABEL " 7" EXIT" GOTO Endit
13180 WAIT
13190 I
13200 Dumpit:
13210 DUMP GRAPHICS TO 401
13220 PRINTER IS CRT
13230 GOTO Exit
13240 Endit:
13250 GRAPHICS OFF
13260 PRINT PAGE
13270 PRINTER IS CRT
13280 DISP "CLEARING DATA FILE"
13290 LOAD "FACETS",Final
13300 Final DISP "BYE"
13310 END
13340 Data: DATASET NAME

```


APPENDIX B. FASTS DATA INPUT GUIDE

A. FILE STRUCTURE

The FASTS data file is composed of a series of BASIC language DATA statements with interspersed lines of comment to aid in file building and readability. When the program is executed, the user is prompted to enter the name of the data file containing the simulation run parameters. The file is then physically attached to the end of the source code and becomes a part of the FASTS program. Statements or commands in subroutine IREP read the parameters from the DATA statements and assign them to the program variables.

Each line containing data begins with the key word DATA. Numerical quantities may be in decimal or integer format and must be separated by commas. Omission of a comma is the most common mistake made in building a data file.

Data elements are read sequentially; hence no parameters may be omitted.

Since the exclamation point, and all information to its right, are ignored during execution, it is used to provide lines for spacing, parameter list headings, and user comments needed to make the file more easily interpreted.

The data file has eight major sections: IREPS; Size; Radar Site; Radar Parameters; Jammer Parameters; Aircraft Initialization; and Aircraft Flight Profile.

1. IREPS

This section contains parameters defining atmospheric conditions.

Parameter Definitions:

K	Equivalent earth radius (dimensionless)
DUTC HT	Altitude of the top of the first trapping layer above the earth's surface (ft)
WIND	Wind speed (knots)

Data Source:

For the standard day, K=1.33 and DUCT HT=0 are used. Parameters for actual conditions may be determined from the IREPS system output. To determine K, run the IREPS program with data for current or predicted atmospheric conditions selecting the Radar Loss Display option. On completion, enter K and depress the ENTER key; the value for K will be displayed. Duct height may be read directly from the IREPS Propagation Conditions Summary display.

2. Size

This section contains time parameters and specifies the number of data elements present in the data file for radars, jammers, and aircraft.

Parameter Definitions:

NAC	Total number of aircraft in the simulation (15 max)
NJM	Total number of jammers types in simulation (15 max)
NRD	Total number of radars in the simulation (15 max)
NACTYP	Total number of aircraft types defined (15 max)

NRDTYP Total number of radar types defined (15 max)
DT Simulation time increment--upper bound (sec)
TFIN Simulation end time (sec)

3. Radar Site

This section contains parameters specifying the type and location of each radar.

Parameter Definitions:

RDTYP Type specification for the radar
RDLAT Y-axis radar location coordinate (nm)
RDLONG X-axis radar location coordinate (nm)
RDALT Radar antenna altitude (ft)

4. Radar Parameters

This section contains parameters for each of the different types of radar systems. Note that parameters for as many as fifteen different types of radar systems may be entered as a data base even though each is not actually used in the simulation.

Parameter Definitions:

RDSCNTYP Radar antenna scan time (sec)
RDBTBTYPE Antenna design (1 = Back-to-Back; 0 = Single)
RMAXTYP Radar maximum range (nm)
RVZEROTYP Detection visibility threshold (dB)
RDERPTYP Radar effective radiated power (dB)
RDFRQTYP Radar frequency (MHz)
RDGANTYP Radar receiving antenna gain (dB)
RDFNTYP Radar receiver noise figure (dB)

RDNBWTYPE	Radar noise bandwidth (MHz)
LOSSTYPE	Radar receiver loss (dB)
RDAZBWTYPE	Radar antenna pattern azimuth beamwidth (deg)
RDAZSLTYPE	Antenna pattern gain in the first side lobe (dB)
RDELBWTYPE	Radar antenna pattern elevation beamwidth (deg)
CSCSQTYPE	Vertical antenna pattern (1 = \csc^2 ; 2 = $\sin x/x$)
DTYPETYPE	Horizontal antenna pattern (1 = Type 1; 2 = Type 2)
HPOLAR	Radar beam polarization (1 = horizontal; 2 = vertical)

Data Source:

Parameter data for most threat radar systems is found in:

Defense Intelligence Agency, Radar Handbook--Eurasian Communist Countries, DST-1710H-507-80-Vol. 3, December 1980

Effective radiated power may be computed as the product of the transmitter power times the gain of the antenna.

Data may be converted to decibel (dB) notation by the use of the following relationship:

$\text{dB} = 10 \log (X)$ where X is the parameter to be converted.

5. Jammer Parameters

This section contains radar jammer parameters listed for each jammer type.

Parameter Definitions:

JMBW	Jammer bandwidth (MHz)
JMFRQ	Jammer frequency (MHz)
JMERP	Jammer effective radiated power

Data Source:

Data for jammer parameters may be found in:

Commander, Operational Test and Evaluation Squadron FIVE,
EA-6B Tactical Employment Guide, OTG 533-01-80 series

6. Aircraft Parameters

This section contains radar cross section data listed for each aircraft type. Up to 360 entries of aspect angle and associated radar cross section may be entered for each aircraft. Note that data for as many as fifteen aircraft may be contained in the parameter file as a data base even if each is not used in the simulation.

Parameter Definitions:

ALPHA Aircraft aspect angle (deg)

RCS Radar cross section gain for ALPHA (dB)

Data Source:

Radar cross section data for aircraft may be found in the tactical manual or supplemental NATOPS manual for each aircraft.

7. Aircraft Initialization

This section contains parameters specifying the type and initial position and velocity for each aircraft in the simulation.

Parameter Definitions:

ACTYP Type specification for the aircraft

ACLAT Y-axis coordinate, aircraft initial position (nm)

ACLONG X-axis coordinate, aircraft initial position (nm)

ACALT Aircraft initial altitude (ft)
 ACHDG Aircraft initial heading (deg)
 ACVEL Aircraft initial speed (knots)

8. Aircraft Flight Profile

This file contains a subfile for each aircraft. Lines within each subfile contain up to fifteen commands for that aircraft and are listed in order of the command initiation time.

Parameter Definitions:

TIME Command initiation time (sec)
 A 9999 entry indicates the end of the an aircraft's profile command list.

CHANGE Command type
 1 = Jam ON
 2 = Jam OFF
 3 = Accelerate (decelerate)
 4 = Climb (Descend)
 5 = Turn
 6 = Home
 7 = Follow

X Command parameter
 Jam ON/Jam OFF Jammer type number
 Accelerate Rate (knots/sec)
 Climb Rate (feet/sec)
 Turn Rate (deg/sec)
 Home Rate (deg/sec)
 Follow Aircraft to be followed

Note: The parameters for accelerate, climb, and turn are signed quantities with negative values indicating decelerate, descend, and turn left.

Y Command target parameter
 Jam ON/Jam OFF Must be 0
 Accelerate New speed (knots)
 Climb New altitude (feet)
 Turn New heading (deg)
 Home Radar site number
 Follow Must be 0

B. DATA FOR DUAL ANTENNA RADARS

Radar systems having two antennas mounted in back-to-back fashion can be simulated by FASTS.

If the variable RDBTB is read as 1 for a radar system, the program will seek data parameters for the second antenna system. These parameters are listed in the data file line directly following the line containing the data for the first system. Data for the following parameters must be entered: RDERPTYP, RDGANTYP, RDAZBWTYP, RDAZSLTYP, RDELBWTYP, CSCSQTYP, DTYPETYP, and HPOLAR.

C. SAMPLE DATA FILE

The following is a sample data file containing multiple radars, radar types, aircraft, and aircraft types:

10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300
Dat: DATASET NAME																													
WASJ																													
K DUCT HT (FT) WIND																													
1.33, 0, 8																													
NAC NJM NRD NACTYP NRDITYP DT TFIN																													
7, 2, 2, 2, 2, 10, 1000																													
Rdrdat:																													
RDAT RDALG RDALT																													
1, 0, 80																													
2, 0, 80																													
RDSCNTYP RDBTBTYP RMAXTYP RUZEROTYP																													
5, 0, 250, 0																													
5, 1, 125, 0																													
RDERTYP RDRFQITYP RDGANTYP RDNBTYP LOSSTYP																													
90, 1000, 40, 10, 10																													
102, 850, 35, 7, 7																													
98, 31																													
RDABZBTYP RDABZSLTYP ROELBTYP CSCSQITYP DTYPETYP HPOLAR																													
4, -20, 4, 0, 1																													
3, -20, 7, 0, 1																													
3.5, -20, 4, 1, 0																													

310 Jmdat:1									
320 1	JMBW	JMFRQ	JMERP						
330 DATA	100,	1000,	800						
340 DATA	150,	900,	14000						
350 1									
360 1									
370 1	ALPHA	RCS							
380 DATA	0,	14							
390 DATA	180,	14							
400 DATA	9999,	00.0							
410 1									
420 DATA	0,	-3							
430 DATA	180,	-3							
440 DATA	9999,	0							
450 1									
460 Acdat:1									
470 1	ACTYPE	ACLAT	ACLONG	ACALT	ACHDG	ACVEL			
480 DATA	1,	100,	0,	5000,	180,	360	JAMMER		
490 DATA	1,	100,	0,	5000,	180,	360	SHOOTER(R)		
500 DATA	1,	100,	0,	5000,	180,	360	SHOOTER(L)		
510 DATA	1,	100,	0,	5000,	180,	360	SHOOTER(C)		
520 DATA	2,	100,	0,	5000,	180,	360	MISSILE(R)		
530 DATA	2,	100,	0,	5000,	180,	360	MISSILE(L)		
540 DATA	2,	100,	0,	5000,	180,	360	MISSILE(C)		
550 1									

560 I	TIME	CHANGE	X	Y
570 I ACFT1				
580 DATA	1,	6,	3,	1
590 DATA	250,	4,	-100,	1000
600 DATA	500,	3,	-5,	300
610 DATA	500,	1,	1,	0
620 DATA	500,	1,	2,	0
630 DATA	740,	5,	-3,	181
640 DATA	660,	5,	3,	180
650 DATA	980,	5,	3,	045
660 DATA	9999			
670 I				
680 I ACFT2				
690 DATA	1,	7,	1,	0
700 DATA	500,	3,	5,	420
710 DATA	500,	5,	3,	230
720 DATA	655,	6,	3,	1
730 DATA	740,	5,	-3,	360
740 DATA	9999			
750 I				
760 I ACFT3				
770 DATA	1,	7,	1,	0
780 DATA	500,	3,	5,	420
790 DATA	500,	5,	-3,	130
800 DATA	680,	6,	3,	2
810 DATA	750,	5,	-3,	360
820 DATA	9999			
830 I				

1 DECEND TO 1000 FT
 300 DECELL TO 300 KTS
 0 JAMMER 1 ON
 0 JAMMER 2 ON
 181 TURN
 180 TURN
 045 TURN

0 FOLLOW JAMMER
 420 ACCEL TO 420
 230 TURN
 1 HOME TO 1
 360 TURN AFTER SHOT

0 FOLLOW JAMMER
 420 ACCEL TO 420
 130 TURN
 2 HOME TO 2
 360 TURN AFTER SHOT

840 IACFT4				
850 DATA 1.	7.	1.	0	I FOLLOW JAMMER
860 DATA 500.	3.	5.	360	I MAINTAIN 360 KTS
870 DATA 700.	5.	-3.	360	I TURN AFTER SHOT
880 DATA 9999				
890 I				
900 IACFT5				
910 DATA 1.	7.	2.	0	I FOLLOW SHOOTER(R)
920 DATA 730.	6.	3.	1	I HOME TO RDR 1
930 DATA 730.	3.	50.	550	I ACCEL
940 DATA 730.	4.	-100.	50	I FALL TO 50 FT
950 DATA 9999				
960 I				
970 IACFT6				
980 DATA 1.	7.	3.	0	I FOLLOW SHOOTER(L)
990 DATA 740.	6.	3.	2	I HOME TO RDR 2
1000 DATA 740.	3.	50.	550	I ACCEL
1010 DATA 740.	4.	-100.	50	I FALL TO 50 FT
1020 DATA 9999				
1030 I				
1040 IACFT7				
1050 DATA 1.	7.	4.	0	I FOLLOW SHOOTER(C)
1060 DATA 700.	6.	3.	1	I HOME TO RDR 1
1070 DATA 700.	3.	50.	750	I ACCEL
1080 DATA 700.	4.	1000.	10000	I CLIMB TO 10000 FT
1090 DATA 9999				

LIST OF REFERENCES

1. Naval Research Laboratory Report 6930, A Guide to Basic Pulse-Radar Maximum Radar Calculation. Part II-Derivations of Equations, Bases of Graphs and Additional Explanations, by L. V. Blake, December 31, 1969.
2. Hoisington, D. B., Electronic Warfare, Naval Postgraduate School, Monterey, California, July 1979.
3. Naval Ocean Systems Center Technical Document 481, IREPS Revision 2.2 User's Manual, by C. P. Hattan, et. al., September 1981.
4. Scolnik, M. I., Introduction to Radar Systems, 2nd edition, McGraw-Hill Book Company, Inc., New York, 1980.
5. Blake, L. V., Radar Range-Performance Analysis, D.C. Heath and Company, Lexington, MA, 1980.
6. Swerling, P., "Probability of Detection for Fluctuating Targets", IRE Transportation Information Theory, IT-6, v. 271, pp. 273-308, April 1960.
7. Naval Research Laboratory Report 6930, A Guide to Basic Pulse-Radar Maximum Radar Calculation, Part I-Equations, Definitions and Aids to Calculations, by L. V. Blake, December 23, 1969.
8. Baker, C. H., Man and Radar Displays, The MacMillan Company, New York, 1962.
9. Johns Hopkins University Applied Physics Laboratory Report NWA-84-027, The Modified Jamming Aircraft and Radar Simulation, by J. E. Hubbs and G. W. Loughran, May 1984.
10. Johns Hopkins University Applied Physics Laboratory Report NAS-84-039, HARM Strike Simulation by D. J. O'Connor and C. M. Barrack, October 26, 1984.
11. White, T. W., Positioning of Jamming Aircraft Using the Integrated Refractive Effects Prediction System, MSc Thesis, Naval Postgraduate School, Monterey, California, October 1982.

INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2. Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5100	2
3. Department Chairman, Code 55 Department of Operations Research Naval Postgraduate School Monterey, California 93943-5100	1
4. Professor N. R. Forrest, Code 55 Department of Operations Research Naval Postgraduate School Monterey, California 93943-5100	1
5. Professor A. F. Andrus, Code 55As Department of Operations Research Naval Postgraduate School Monterey, California 93943-5100	1
6. LCDR Paul Fischbeck, Code 55Fb Department of Operations Research Naval Postgraduate School Monterey, California 93943-5100	1
7. The Johns Hopkins University Attn: C. M. Barrack Applied Physics Laboratory Laurel, Maryland 20707	1
8. Naval Ocean System Center Attn: C. P. Hattan San Diego, California 92152	1
9. Naval Tactical Support Activity Attn: CDR F. O. Barrett P.O. Box 1042 Silver Spring, Maryland 20910	1

- | | | |
|-----|-------------------------------------|---|
| 10. | Dr. M. Leonardo | 1 |
| | Naval Air Development Center | |
| | Warminster, Pennsylvania 18974-5000 | |
| 11. | LCDR Karl. A. Kail | 1 |
| | Fleet Liaison Action Group | |
| | Naval Air Development Center | |
| | Warminster, Pennsylvania 19974 | |

END

FILMED

12-85

DTIC